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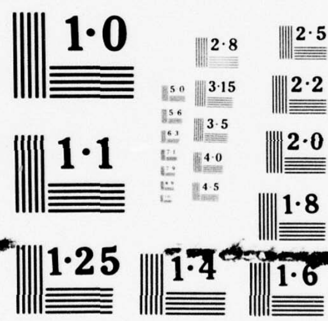
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CORROSION PREDICTABILITY IN F-4 AIRCRAFT ASSIGNED TO THE PACIFIC AIR FORCES

Jerrold B. Harrington, Captain, USAF
Jacob Teomy, Captain, IAF

LSSR 19-77A

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT-LSSR-19-77A	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) CORROSION PREDICTABILITY IN F-4 AIRCRAFT ASSIGNED TO THE PACIFIC AIR FORCES ,		5. TYPE OF REPORT & PERIOD COVERED (9) Master's Thesis,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Jerrold B. Harrington Captain, USAF Jacob Teomy Captain, IAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Graduate Education Division School of Systems and Logistics Air Force Institute of Technology, WPAFB OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Research and Administrative Management (LSGR) AFIT/LSGR, WPAFB OH 45433		12. REPORT DATE (11) June 1977
		13. NUMBER OF PAGES 79
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (12) 93p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES APPROVED FOR PUBLIC RELEASE AFR 190-17. JERRAL F. GUESS, CAPT, USAF Director of Information		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Corrosion, corrosion prediction, statistical models, regression analysis, corrosion control		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Thesis Chairman: Leslie J. Zambo, Major, USAF		

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Corrosion has become a serious problem in PACAF due to inadequate management attention in the areas of facilities, training, and manning. The purpose of this study was to construct a mathematical model useful for predicting base-level corrosion control man-hours. The utility of such a model would allow the manager to forecast his requirements for corrosion maintenance. Statistical analysis involved least squares multiple linear regression. Independent variables included: (1) aircraft historical data such as airframe hours, age, assignment history, and MDS; (2) maintenance data such as PDM hours, contract corrosion control hours, and time since last PDM; and (3) corrosion severity indices. Data on the variables used in the analysis were gathered from the AFLC GO-98 computer data bank and at Headquarters PACAF. Studied in this research were F-4 aircraft at four PACAF bases: (1) Kadena AB, Japan; (2) Clark AB, P.I.; (3) Kunsan AB, Korea; and (3) Osan AB, Korea. The results showed a statistically significant regression model; however, a relatively high standard error of the estimate limited its usefulness.

LSSR 19-77A

CORROSION PREDICTABILITY IN F-4 AIRCRAFT ASSIGNED TO THE PACIFIC AIR FORCES

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degrees of Master of Science in Logistics Management

and Master of Science in Facilities Management

By

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June 1977

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This thesis, written by

Captain Jerrold B. Harrington

and

Captain Jacob Teomy

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN FACILITIES MANAGEMENT
(Captain Jerrold B. Harrington)

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(Captain Jacob Teomy)

DATE: 15 June 1977

Leslie J Zambo

COMMITTEE CHAIRMAN

ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the encouragement and support provided by our thesis chairman, Major Leslie J. Zambo. We also wish to acknowledge Hq PACAF for their assistance and sponsorship in carrying out the thesis effort.

A special thank you goes to our families for their patience and understanding during this ordeal. Finally, we wish to thank Mrs. Dee Babiarz for a fine job of turning our scribbling into finished product.

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INTRODUCTION

Statement of the Problem

> Corrosion is one major wear-out phenomenon which significantly influences the cost of ownership of Air Force systems.
>
> This problem is neither new nor unique to Air Force equipment; however, it must be faced and solved more effectively than it has been in the past. If programs are to succeed in this era of high and growing operating and support costs, managers must be aware of the long-term cost implications of corrosion, as well as interested in the prevention and solution of these problems. This problem is too important to be left solely for engineering specialists to solve, and management must involve itself in the issues which such problems raise [27:13].

With these words, the U.S. Air Force Inspector General touched upon the major weakness of the AF corrosion control and prevention program--lack of effective management! When the corrosion control program is not effectively managed, backlogs of work pile up creating a serious situation. Corrosion, left untreated, gets progressively worse with the passage of time. The longer it remains undetected or untreated, the longer it takes to repair and the higher the expense incurred. More critical than this, untreated corrosion weakens structural members to the point of catastrophic failure, endangering the lives of crew members and others. Experience has shown that corrosion

control catch-up is an expensive alternative to a sound corrosion prevention program (10:36).

For a manager to be effective, he must have some means of planning for the future needs of his organization. In corrosion management, it would be beneficial to be able to isolate and quantify those factors which are useful in predicting corrosion damage. With this information, a predictive model could be devised which would aid the manager in forecasting requirements for inspection, maintenance, training, facilities, and manning (19:1).

Background

Air Force Technical Order 1-1-2 states:

> Corrosion or deterioration of metal starts the instant the fabrication or manufacturing process is completed and continues until the material is exhausted or salvaged. The speed of the deterioration or corrosion will depend on many factors but primarily on the type or chemistry of the material used; environment to which it is exposed; fabrication and/or assembly methods used; heat treatment; and degree or method of protection or preventive measures including such things as shot peening, etc., taken to retard the corrosion process. The design or project engineer will be concerned with all the design factors, i.e. mission, reliability, maintainability, cost, and corrosion which can have a detrimental effect on the equipment. On the other hand, maintenance personnel will be concerned with sustaining the features built in by the design engineer at a reasonable cost. Maintenance personnel in accomplishing structural repair will find that about 50 percent or more of actions or work will be related to corrosion or deterioration in some way [22:1-1].

Table 1 shows the most common types of corrosion found in Air Force equipment.

Table 1

Common Types of Corrosion Found on AF Aircraft[1]

Type	Description
A. Uniform attack	Occurs over the entire surface of a metal and is caused by direct action with the environment.
B. Pitting	A form of severe localized attack which can completely penetrate a metal or alloy. This type of corrosion is most destructive because the pits are small and hard to detect.
C. Intergranular (exfoliation)	A concentrated attack on the grain boundaries of a metal. It can be caused by differences in composition between the grain boundary and the interior of the grain or by impurities which gather at the grain boundaries.
D. Galvanic	Occurs when dissimilar metals or alloys are in contact and a conductive solution is present.
E. Crevice corrosion	A type of localized attack occurring wherever crevices are formed, i.e. under gaskets, bolt heads, rivets, etc. This type is difficult to detect because of its location.
F. Stress corrosion cracking	The result of constant tensile stress and corrosion occurring simultaneously. This type is a serious problem for the Air Force because it is generally difficult to recognize before safety factors have been exceeded.

[1]For a more extensive discussion of the various types of corrosion, see bibliographical entries: 5, 21, and 22.

Table 1 (continued)

Type	Description
G. Corrosion fatigue	A special case of stress corrosion in which the stress is cyclic in nature. The material fails due to a reduction of the fatigue limit as a result of corrosion.
H. Filiform corrosion	Gets its name from the numerous threadlike filaments which are formed when water and oxygen get under an organic coating.
	[21:24-26]

General recognition by the United States military and the American scientific communities of corrosion as a significant problem can be traced to the period during World War II (8:vii). While corrosion has always been a problem with which we have lived, it was not until this period that destruction of equipment to such a great extent was witnessed.

> The theaters of operation in World War II, which encompassed virtually every extreme in climate, provided conditions which led to deterioration of equipment on a scale never before experienced by any major military organization [17:2].

Since this time, the Department of Defense has focused a great deal of attention on the corrosion problem.

In the early 1940's, the National Defense Research Committee created the Army-Navy Deterioration Steering Committee to mount a coordinated attack on corrosion. In 1943, the Tropical Deterioration Information Center was established. In 1945, the usefulness of these organizations was recognized which led to the creation of more permanent organizations: the Joint Army-Navy Deterioration Prevention Committee and the Prevention of Deterioration Center under contract with the National Research Council of the National Academy of Sciences. The Department of the Air Force joined ranks with the Army and Navy in supporting research into the prevention of corrosion when it became a separate service in 1947 (8:vii-viii).

With the trend toward smaller defense budgets expressed as a percentage of Gross National Product and the resulting need to reduce maintenance costs while simultaneously maintaining military effectiveness, the costs associated with corrosion damage have continued to draw attention. In 1974, the Air Force established the Maintenance Posture Improvement Program (MPIP) with the stated goal to initiate ". . . a program to reduce maintenance manpower and material costs and increase effectiveness of mission support [28:1]." The Air Staff directed that MPIP be expanded to include all aspects of the corrosion problem (17:3).

> Tasking will include working level panels . . . to actively probe, evaluate, and present recommendations on all possible means/alternatives available to promote and develop a more effective [corrosion prevention] program for the Air Force. All efforts will be focused on identifying changes and improvements that will produce reductions in corrosion damage and associated costs [24].

Justification

Research in the area of corrosion predictability can be justified for several reasons. Air Force policy states:

> An effective corrosion prevention and control program will be continuously pursued throughout all maintenance activities to enhance safety, extend service life, and to reduce costs, repair man-hours, and systems and equipment downtime.
>
> Corrosion prevention and control will be a primary design criterion in the development, acquisition, and modification of weapon systems and subsystems [23:1].

Being able to predict the rate of corrosion at each air base would enhance stated Air Force policy by helping to prolong the life of our present aircraft resources through efficient scheduling of corrosion prevention measures. Research in corrosion prediction could also result in increased accuracy in our present life cycle cost (LCC) models. Lastly, corrosion prediction will help the manager forecast more accurately his resource requirements.

<u>Resource conservation</u>. Given the economic constraints and long lead-times associated with new military acquisitions, a great deal of emphasis has been placed on prolonging the lives of many of the weapon systems currently in use. Major modifications have been made to extend the operational life of aircraft, such as the B-52, far longer than envisioned when they were acquired (18:10). Colonel L. C. Setter points out the effect corrosion has on the lifetime of aircraft:

> We used to think the major problem regarding continued airworthiness of our aircraft was the condition of wear or wearout. Since many of our weapons systems were increasing with age, we now have B-52's that are roughly 20 years old, F-4's that are fifteen, even our C-5's are showing signs of old age; we thought the wear problem was a very serious one and we thought that was the reason we brought airplanes into the depot. Our technical evaluations over the past few years revealed that wear is not nearly as destructive a factor as corrosion. Corrosion presents a greater problem than wear due to the unknown factors which weigh in the situation and our inability to track or predict corrosion. We don't know how to project that an airplane is going to be corroded [18:10].

Since 60 percent of repair costs are corrosion related and total man-hour costs, exclusive of repair parts, amount to one-half billion dollars annually, there is considerable incentive to seek improved procedures (19:1). Basing inspection and programmed maintenance intervals upon the predicted risk of corrosion is one method which could decrease these expenditures. Thus, research in corrosion predictability could result in lower overall maintenance costs and, would also contribute to lower life cycle costs.

Improved life cycle cost models. Techniques to estimate the total cost of a system from inception to disposal have come about due to Congressional and Defense Department demands for more visibility and control of systems cost during acquisition and operation. Included in these life cycle costs is the amount spent for operation and maintenance (O&M) of the system. Since O&M costs can account for as much as 60 to 70 percent of the total cost for these systems, accurate modeling of these costs are essential for valid LCC estimation (3:20-28). Moore encapsulates a problem with present LCC models as follows:

> . . . , a very powerful tool for creating understanding of the importance of corrosion is Life Cycle Costing, particularly when LCC models are designed to be sensitive to failure modes and correctly allocate costs. However, the models which we are presently using do not seem sensitive to corrosion or fatigue, and work needs to be done in our modeling techniques to enable us to make decisions on program finish systems, design details, and how they will influence total system cost [14:27].

Life cycle cost prediction for military systems has all the usual problems of economic forecasting, plus those of predicting cost associated with corrosion. When the service life of components subject to corrosion can be predicted with the accuracy which fatigue life predictions can be reached, more accurate life cycle cost estimation will result (13:52,53). Research in corrosion prediction should assist in increasing the accuracy of our LCC models.

Increased management efficiency. In addition to enhancing LCC techniques and scheduling efficiency, the ability to predict the order of magnitude of the corrosion prevention and control effort at each base will help increase the efficiency of our managers. The efforts of the Air Force in general and PACAF in particular have been less than adequate in managing the corrosion problem. This may stem from the belief at base level that all but the most routine corrosion maintenance should be carried forward until that aircraft is scheduled for major overhaul at the programmed depot maintenance (PDM) facility. This, in turn, may be due to the extensive downtime required for corrosion repairs (12:2). Whatever the reason, the best policy is to prevent corrosion. If ignored, it becomes progressively worse, spreading to the very core of affected structural members. In PACAF, the situation presently rivals that which faced SAC in 1973 with its B-52s in Guam.

> The extent and severity of B-52 corrosion first became known in mid-1973 when the 43 SW Anderson AFB, Guam, requested depot assistance to overcome a corrosion backload of 41,000 man-hours.
> . . . The costly depot and field team corrosion programs, begun in 1973, ultimately required the in-house resources of two depots plus field teams from four depots working simultaneously by mid-1974 to keep abreast of scheduled and unscheduled workloads. Heavy B-52 depot corrosion work continued through 1975 and the first half of 1976. Since the B-52G corrosion program was completed 20 July 1976, the remaining depot corrosion repairs are accomplished during programmed depot maintenance (PDM) [10:34].

This is an example of the excessive costs which can be incurred for not keeping on top of the corrosion problem. In PACAF, the backlog of corrosion repairs on F-4 aircraft is extensive and has been caused by lack of effective management in the following areas:

1. Facilities. PACAF Regulation 66-19 states:

> It is the PACAF goal to establish adequate corrosion control facilities at every active base in theater within the next 5 years. Bases will establish construction programs to upgrade existing facilities or to construct new facilities to meet this end.
> a. Three facilities are required at each active base:
> (1) An aircraft wash rack(s) (as required) conforming to Air Force Definitive Drawing AD39-01-83 capable of sustaining aircraft wash operations year-round.
> (2) A corrosion control shop facility meeting the requirements of AFM 86-2, section F.
> (3) An enclosed aircraft paint hangar capable of sustaining touchup paint operations on assigned aircraft year-round.
> b. Each facility must meet minimum Occupational Safety and Health Act (OSHA)/Environmental Protection Agency (EPA) requirements, and must be equipped with requisite ventilation, lighting, wiring, utilities, dip tanks, drain systems, spray booths, air conditioning systems, fire suppression, personnel safety, and pollution control systems to meet normal corrosion control operational requirements [25:4].

This regulation was published 3 December 1976, and defines an overall corrosion control program for PACAF. The publication of PACAFR 66-19 shows that the present USAF upper level management is acutely aware of the present corrosion situation and has taken steps to improve it. A great deal of work is needed in the facilities area as the current situation reveals.

The present corrosion control facilities at the four F-4 bases are in need of major repair/updating.

> The corrosion control facilities at Kunsan AB and Osan AB, Korea have no area for the painting of aircraft. Washrack facilities have inadequate heating systems for washing aircraft in winter months and installed equipment for washing aircraft is unserviceable. Drainage and skim tanks for wash/paint strip residue is nonexistent. Facilities at Clark AB, P.I. are also inadequate. The lack of a covered washrack coupled with the existing environmental conditions prevent effective cleaning of aircraft/AGE. The extensive rainfall, high temperature, and humidity curtails painting and corrosion control maintenance in an unprotected environment. Facilities that meet (OSHA) standards must be constructed.
>
> The facility at Kadena AB, Okinawa meets all (OSHA) standards; however, the location of the washrack is uneconomical. Towing aircraft two miles, across two active runways, for washing costs excessive man-hours and creates a safety hazard. Construction of a covered washrack in the immediate area of the aircraft is needed [12:3].

The upgrading/construction of corrosion control facilities must be given immediate attention. Effective corrosion control maintenance can not be accomplished in sub-standard facilities (12:3; 7).

2. <u>Training</u>. One of the main reasons why the current backlog of major corrosion maintenance actions

exists in PACAF is the lack of adequate training given to personnel in inspection, detection, and documentation of corrosion. This does not apply so much to the corrosion control specialists as it does to other flight line personnel who are not familiar with the various forms of corrosion. Such personnel as quality control inspectors, fuel systems and egress technicians, and crew chiefs need training in detecting corrosion where it actually occurs on the aircraft at their base and in documenting these discrepancies correctly on the AFTO Form 349 (see Appendix D).

PACAF has taken action to overcome the shortcoming in the training of personnel with regard to corrosion identification, detection, and documentation. PACAFR 66-19 establishes a training program which includes corrosion prevention and control familiarization for all incoming maintenance personnel. It states:

> This one-time course should be 6-8 hours in length, when course materials are available to justify the length, and should be tailored to the specific functional area(s) in which the personnel will work. Particular emphasis will be placed on peculiar system corrosion problems, and will also cover corrosion identification, prevention, responsibilities, techniques, reporting, and documentation procedures, and technical data [25:4].

This training program is slated to be in operation by June 1977, and should greatly increase the effectiveness of the corrosion control program at each PACAF base.

3. <u>Manning</u>. Prior to the early 1970's, much of the corrosion work in PACAF was done by commercial contractors.

> Low labor rates made contracting more economical than constructing modern base corrosion facilities, therefore no action was taken to update facilities to meet minimum (OSHA) standards. Authorized manning did not reflect the quantity of aircraft and support equipment requiring corrosion treatment. Special tools, and equipment, were not requisitioned for an effective corrosion facility at base level.
>
> In the early 1970's our corrosion problems began to surface. Contractual labor cost continued to increase to an uneconomical rate. Base corrosion facilities were inadequate for effective corrosion control maintenance. Authorized and assigned manning did not reflect the manpower required to effectively maintain corrosion on aircraft and support equipment [12:2].

This is still a problem because PACAF does not have sufficient manpower to alleviate the huge backlog of F-4 corrosion. Under these conditions, it is difficult to document the need for additional permanent manning.

> The present manning may be adequate to maintain the fleet if all the aircraft were in good condition but, we are so far behind in repairing major corrosion damage, we can't tell [7].

It would be possible to reduce the scope of these problems if the needs for manning, training, and facilities at each base could be accurately forecast. If the man-hours required to carry out the corrosion control program at a base in future years could be accurately forecast based on readily available parameters, requests for additional manning and facilities could be justified and plans could be made for the required training.

Related Research

Corrosion is the process by which materials deteriorate to a more thermodynamically stable condition through electrochemical interaction with their environment (13:48). The Armed Forces and private industry spend millions each year combatting the effects of corrosion (5:2). Various efforts, both past and ongoing, have been funded to arrive at a method to predict corrosion rates. Some of the Air Force efforts will be discussed in this section.

One project, known as PACER LIME, has as its aim to derive a corrosion severity factor (CF) for each USAF base. As a first approximation of the values of these CFs, an interim value was assigned to each air base predicated on qualitative observations as to how weather conditions affect corrosion rates. Values of those interim CFs for the PACAF bases of interest to this research effort are shown in Table 2. In project PACER LIME, tests are presently being conducted to validate these subjective values of the corrosion severity factor through experiments performed with several aircraft alloys at various locations worldwide. The experiments entail exposing bare plates of alloys to the elements and measuring their weight loss over time due to corrosion. The results of these tests along with climatological and air pollution data will be used to determine new values for the CFs (9:2). The Air Force uses

the present interim CFs to determine wash cycles and corrosion inspection intervals for aircraft and equipment at each base (23:22).

Table 2

Corrosion Severity Factors
(PACER LIME)

Base	CF
Kadena AB, Japan	1.83
Clark AB, PI	2.00
Osan AB, Korea	2.50
Kunsan AB, Korea	1.83
	[9:36]

Dr. Robert Summitt is conducting a research effort at Michigan State University designed to develop a method for scheduling depot maintenance and predicting costs to replace PDM. Dr. Summitt's study entails correlating C-141 maintenance data and various other environmental factors to develop improved models for predicting the nature and frequency of corrosion-related repair as well as guidelines for minimizing corrosion damage (20:1-3).

Attention has also been directed at determining the relationship between environmental factors and variable corrosion damage experience. A preliminary study by

Major Thomas Moore compared maintenance man-hour costs for the F-4E engine starter and the KC-135 Doppler radar at three midwestern bases. Despite similar weather conditions, significant differences among the bases were found, suggesting atmospheric pollution may have an important role. Major Moore's results indicate that it is possible to predict repair costs and needs if the appropriate risk factors are known and quantified (15:17-24).

Objectives and Scope

The objectives of this research are threefold. The first is to establish if a linear relationship exists between base-level corrosion control man-hours and selected independent variables. The second objective is to formulate a regression model, based on these independent variables, which will be useful in forecasting base-level corrosion man-hours for each of the four PACAF F-4 bases. As a third objective, the variables will be identified whose net or marginal contributions to the explanatory power of the model are significant.

In order to develop a study of manageable proportions and in a reasonable time period, it was necessary to restrict the scope of the research. Because of command interest in corrosion predictability and the availability of data, the study was limited to PACAF assigned F-4 aircraft.

Research Hypothesis

A number of variables exist which can be used to predict the yearly base-level maintenance man-hours expended on corrosion.

Chapter 2

METHODOLOGY

The basic approach used in this research effort consisted of ascertaining which variables have an effect on corrosion control man-hour costs. The data on selected variables were collected, analyzed, and used to develop a multiple linear regression model. The relationships found among the variables were used to develop a model for predicting base level corrosion man-hour costs. It was expected that the results of the analysis would provide a statistically significant mathematical model.

Population

The population was defined as all present and future F-4 aircraft in the U.S. Air Force inventory. The F-4 aircraft is a twin engine jet fighter which is deployed worldwide. Mission design series of the F-4 in the USAF inventory include the F-4C, F-4D, F-4E, and RF-4C, the latter being used in a reconnaissance role.

Sample

The sample selected for study consisted of a census of all F-4 aircraft assigned to the Pacific Air Forces during the time period 1974-1976. The decision was made to

limit the sample in this manner due to the command interest shown by PACAF and the availability of data to conduct the analysis. However, since aircraft from other commands and operating locations were not included in the sample, no attempt was made to make inferences to the population based on the results of this research.

The original sample of 170 aircraft was reduced because of data considerations. PDM and contract corrosion control (CCC) records were incomplete. Aircraft for which data was not available were eliminated from the sample. In addition, since base-level corrosion control man-hours in CY 1976 was the dependent variable, all aircraft which underwent PDM during that year were eliminated from the sample. The resulting sample consisted of eighty F-4C, F-4D, F-4E, and RF-4C aircraft from four PACAF air bases.

Data Acquisition

The data used to describe the variables in the multiple linear regression analysis (MLR) were obtained from sources within the Air Force. The corrosion factors (CF) for all USAF bases were acquired from the Air Force Logistics Command (AFLC) Corrosion Management Office. The CFs are interim values taken from the PACER LIME project.

Base-level corrosion maintenance man-hours and PDM dates were obtained from the GO-98 computer data bank at the San Antonio Air Logistics Center at Kelley AFB, Texas.

Data on the remaining predictor variables such as age, airframe hours, the number of months each aircraft was assigned to the different PACAF bases, PDM and contract corrosion control man-hours, etc., were obtained at PACAF Headquarters, Hickam AFB, Hawaii.

Data Description and Validity

Sufficient data to conduct the analysis was obtained with considerable difficulty. Variables which were constructed from the data are defined and described below. Next is a discussion of the data which, for several reasons, was not obtained, and what impact the exclusion of this data would have on the results of the analysis.

Base-level corrosion control man-hours. This was chosen as the dependent variable. Historically, there have been problems in collecting this type of maintenance data. There are only two how-malfunctioned codes (AFM 66-1) which apply to corrosion maintenance: 170--corroded, mild to moderate, and 667--corroded, severe. Dr. Summitt and others have found, however, that when maintenance technicians document corrosion-caused damage, they either do not recognize it as such and code it on the AFTO Form 349 as some other how-malfunction code or they believe that corrosion was only a contributing factor, with the same result (20:9-10). Air Force Technical Order 1-1-2 cautions:

> Corrosion is often ignored as the cause for the maintenance action; and when reported (AFM 66-1), another reason is often given for accomplishing the work. Many times the reason for such reporting is that corrosion is not an obvious factor to the mechanic performing the work. This can be attributed to a lack of training or the complexity of the process. Stress corrosion cracking and corrosion fatigue are two types of failure that are often improperly reported. It is often impossible to determine by visual examination the cause of the crack. It may be stress corrosion, corrosion fatigue, simple overload, improper heat treatment, or a combination of these causes. If corrosion is evident in the area of the crack, it is usually an accelerating factor, and the failure should be reported as corrosion [22:1-1].

An even more damaging practice in recording maintenance history on the AFTO Form 349 is the failure of the technician to look up the how-malfunction code. The technician instead enters the code for "general maintenance." PACAFR 66-19 also addressed this problem:

> Documentation of maintenance actions in corrosion prevention/control will be accurately coded as to what malfunctioned, how the malfunction occurred, when it was discovered, and how it was corrected. Proper reporting will assure adequate manning, equipping, training, and parts/materials procurement. Of primary concern is the use of how malfunction (How-Mal) codes 170, mild or moderate corrosion, and 667, severe corrosion. Any time equipment requires maintenance as a direct result of corrosion, code 170 or 667 will be used with work unit code of the item requiring treatment. For example, if a cannon plug is shorted because it is corroded, the How-Mal code for the discrepancy will be 170 (corroded), not 615 (shorted). In addition, personnel should guard against use of codes such as 230 (dirty), 117 (deteriorated), 306 (contamination), 520 (pitted), etc., when code 170/667 (corroded) more accurately describes the condition [25:4-5].

The problem of accurate documentation of maintenance history caused Dr. Summitt to use a number of How-Mal

codes to represent what he thought more accurately described the actual corrosion maintenance experienced at base level (20:9-10). For this research, the same collection of How-Mal codes were used and are tabulated in Table 3. Records for each PACAF F-4 for CY 1976 were screened and the summation of the man-hours expended under each of the How-Mal codes was used to represent total man-hours devoted at base-level to corrosion control. Despite the possibility that the data may not be 100 percent accurate, its validity was accepted subjectively until such time as the analysis of the results would suggest otherwise. Dr. Summitt believed . . .

> Without question, this "corrosion" file contains some records which are not related to corrosion. Editing the file to remove them appears to be less important, however, than it did earlier in the study for several reasons. Except for the How-Mal "cracked", the number of such records has been found to be small (about 1%) when compared with the total. In the case of the "cracked" category, there is considerable reason to believe that corrosion is a factor in a majority of cases (i.e., stress corrosion cracking and corrosion fatigue). Further, the chronological pattern of the several How-Mal codes parallels fairly well that of those identified specifically as corrosion. Finally, we still are of the opinion that all categories selected are indeed corrosion related, even when non-metallic materials are involved [18:9-13].

<u>Base-level corrosion inspection man-hours</u>. This independent variable was obtained from the same data source used for base-level corrosion maintenance man-hours. The variable represents the total man-hours expended in work unit code (WUC) 2000, corrosion inspection (AFM 66-1). It was

Table 3

How-Malfunction Codes Selected to Represent Total Base-Level Corrosion Maintenance

How-Malfunctioned	Description
117	Deteriorated
170	Corroded, mild to moderate
190	Cracked
230	Dirty, contaminated or saturated by foreign material
520	Pitted
605	Crazed
617	Sulphidation
622	Wet, condensation
667	Corroded, severe
846	Delaminated
865	Protective coating, sealant missing
910	Chipped

difficult to predict what affect increased man-hours spent in corrosion inspection would have on total corrosion maintenance man-hours. It could be argued that with less inspection, less corrosion would be found, and less corrosion maintenance would be needed. On the other hand, more inspection would mean that corrosion would be found in its earlier stages when corrective maintenance would not require as many man-hours.

Age. A portion of the tail number of each aircraft designates the year of manufacture. A mid-year convention was used which considered the age of each aircraft as the difference between the middle of the year of manufacture and the middle of 1976, the year in which data for the dependent variable was accumulated. As an example, aircraft #63-00744 was manufactured in 1963. Its age was determined to be 13 years based on the difference between mid-1963 and mid-1976.

Airframe hours. Airframe hours is defined as the total flying hours logged on each aircraft as of 31 December 1976. This data was obtained from flight records maintained by the F-4 monitor at PACAF Headquarters.

Mission design series (MDS). Information concerning MDS was obtained from the aircraft historical records at PACAF Headquarters. The MDS for the four aircraft studied in

this analysis were F-4C, F-4D, F-4E, and RF-4C. Categorical (dummy) variables were used to encode this information in the data file. For example:

X_a = 1, if aircraft is an F-4C, 0 otherwise,

X_b = 1, if aircraft is an F-4D, 0 otherwise,

X_c = 1, if aircraft is an F-4E, 0 otherwise.

If X_a, X_b, and X_c are all zero, the aircraft is an RF-4C. Thus, the RF-4C is considered the basis and any coefficient associated with X_a, X_b, X_c denotes a difference in base-level corrosion man-hours due to the aircraft being other than an RF-4C. It was believed that differences would occur among MDS due to differences in mission profiles and alert requirements.

<u>Months at the various bases</u>. Aircraft historical records listed the base of assignment for each aircraft since the date of its assignment to PACAF. The number of months spent at each of the four F-4 bases and at bases in Thailand (F-4's are no longer stationed there) during the time frame CY 1974 to CY 1976 were included in the data file. The cummulative effects of being stationed at the various locations was expected to have an affect on total corrosion man-hours.

Current base of assignment. This variable was expected to explain any variance in maintenance procedures among bases. Categorical variables were again used with Clark AFB, P.I., being the base variable.

Time since last PDM. Major maintenance and Time Compliance Technical Order actions are often accomplished at periodic programmed depot maintenance (PDM). Table 4 shows the intervals specified for the four MDS used in the analysis. Extensive corrosion maintenance and painting is accomplished during PDM and it was believed that as time elapsed since the last PDM, corrosion would increase. Between FY 73 and FY 76, many aircraft received major contract corrosion control treatment between PDM overhauls. This work was accomplished at the Kadena AB facility in FY 74 and in Tainan, Taiwan, during FY 75 and FY 76. Since this also represented extensive corrosion control work, the date from either the last PDM or from the last contract corrosion control, whichever was later, was used as this predictor variable.

This information was obtained from manual records kept by the contract administrator in Taiwan. Based on interviews with the personnel responsible for tracking, the accuracy and validity of this data were judged to be excellent (7).

Table 4

PDM Cycle (In Months) For
F-4 Aircraft

MDS	FY 77	FY 78	FY 79
RF-4C	54	54	54
F-4C	30	36	36
F-4D	48	48	48
F-4E	36	36	36

[Source: TO 00-25-4]

PDM man-hours. This variable represents the number of man-hours expended on the aircraft during its last PDM. If the aircraft had gone through contract corrosion control since it left PDM last, a zero value was used. It was assumed that the more man-hours expended during PDM, the fewer hours would need to be spent on base-level corrosion control. Ideally, the PDM man-hours should be broken out as expended for corrosion or some other How-Mal code. This procedure was begun only recently (7). The data was obtained from manual records kept in Tainan, Taiwan.

Contract corrosion control (CCC) man-hours. This variable is similar to PDM man-hours except the hours in CCC were tabulated instead.

Corrosion severity factor (CF). This variable was obtained from the interim results of the PACER LIME project. The validity of these factors to predict the environmental effect on corrosion at each base is accepted subjectively due to the dependence on qualitative observation for its determination. This variable was expected to be highly correlated with the categorical variables representing current base of assignment. For this reason, these two variables, base of assignment and corrosion severity factor, were not entered into the program simultaneously. Each was entered separately with the other variables and the one which resulted in the higher explanatory model was chosen.

Description of Variables Not Examined

The foregoing was a discussion of the variables which were used in the attempt to formulate the predictive model. Following is a discussion of variables which may have potential value as predictors of base-level corrosion man-hours, but for which current data could not be obtained.

Air pollution data. It has been shown that air pollution may have an effect on the rate of corrosion (15). The amounts of sulphur dioxide (SO_2) and hydrocarbons in the air are presently tracked by the Environmental Protection Agency (EPA) in many areas in the United States but, as

yet, no tracking of this data is accomplished in the Pacific areas considered in this study (6). Any future attempts to model corrosion experience should include some consideration for the effects of pollution.

Manning. A study in the prediction of base-level man-hours should take into consideration the manning levels at the various bases. For this study it was assumed that the manning levels were equal for each of the four bases; however, no data was available to confirm this. As historical data on manning in the various Air Force Specialty Codes (AFSC) is retained only six months, data for the time period of this analysis was not on hand (2).

Washing. Aircraft washing is an important facet of the base corrosion prevention program. The man-hours devoted to washing might be helpful in predicting corrosion man-hours. Intuitively, corrosion man-hours should decrease with a greater emphasis on the washing program (29:8-5). PACAFR 66-19 establishes washing intervals based on corrosion severity indices at each base. Unfortunately, these man-hours are not tracked at major command level and are available through the base-level inquiry system (BLIS) for the preceding six months only. The effect of not being able to include these variables in the analysis was expected to lower the explanatory power of the model.

Developing the Model

The research was an attempt to show that a significant linear relationship exists between total yearly base-level corrosion control man-hour expenditures and the predictor variables mentioned above. To accomplish this, a model was constructed using multiple linear regression (MLR).

Overview. Simple linear regression analysis is a tool by which it is possible to fit a curve, representing the behavior of the dependent variable, to data points which correspond to values of an independent variable. MLR is an extension of simple regression to take account of the effect of more than one independent variable on the dependent variable. The main reason for using MLR analysis is to reduce the bias that might result if an uncontrolled independent variable that affects the dependent variable were ignored (30:306).

The general form of the multiple regression model is:

$$Y = B_o + B_1X_1 + B_2X_2 + B_3X_3 + \ldots + B_nX_n$$

where: Y = base-level corrosion control man-hours per aircraft,

X_i = parameters based on aircraft historical data, maintenance data, CFs, etc., and

B_i = the coefficients of regression.

Assumptions. The following assumptions are needed to justify using MLR to fit the curve (regression line) to the independent data points.

1. The error terms which are the vertical distance between each data point and the regression line, are statistically independent.

2. The expected value of these error terms is zero measured with respect to the regression line.

3. The variation of the error terms is constant for each independent variable X.

4. The error terms are distributed normally about the regression line.

5. The number of sample observations is greater than the number of estimated population parameters.

6. Sample observations must be linearly independent.

7. The values of the independent variables are measured without error, that is to say, all measurement error is associated with the dependent variable (11).

Manipulating the Model

A computer program, the Statistical Package for the Social Sciences, commonly known as SPSS, was available for use in constructing the model through MLR analysis. The subprogram regression was used which computes a sequence of linear regression equations in a stepwise manner. At each step, the independent variable is included which contributes most to that portion of the variance in the dependent variable which is explained by the model. This procedure is called forward inclusion (16:345).

Design to Meet Objectives

The objectives of the research were to (1) determine whether a linear relationship of base-level corrosion man-hour expenditures exists with the independent variables associated with aircraft historical data, maintenance data, and corrosion severity factors, (2) develop a predictive model if a linear relationship exists, and (3) identify the independent variables whose net or marginal contributions to explained variation are significant. A classical hypothesis test was performed to show that a relationship exists between the dependent variable, Y, and the independent variables, X_i.

$$H_0: \ B_1 = B_2 = B_3 = \ldots = B_n = 0$$

$$H_1: \ \text{at least one } B_i \neq 0$$

The hypothesis was tested using the statistical F test. This test compared the F statistic found using:

$$F_{regression} = \frac{\text{variation explained by regression}}{\text{unexplained variation}}$$

with an F statistic found in the standard statistical tables. This latter value, called $F_{critical}$, must be absolutely less than $F_{regression}$ in order to reject H_0 and conclude a statistically significant relationship exists between the dependent and independent variables. The criteria used to determine statistical significance will be a 95 percent level of confidence in the result. This level of confidence is commonly used in statistical analysis

and is specified in AFM 25-5 for use in the Air Force management engineering policies and procedures for developing manpower standards and conducting management advisory studies (26:i). If the overall model is found to be significant, each regression coefficient, B_i, remaining in the model will be tested at the 95 percent level to see if it significantly adds to the explanatory power of the model. This test, also using the statistical F-test, is conducted on the following hypothesis:

$$H_o: \; B_i = 0$$

$$H_1: \; B_i \neq 0$$

$$F_{statistic} = \left[\frac{B_i}{S_{B_i}} \right]^2 = \left[\frac{B_i}{\text{standard error of } B_i} \right]^2$$

To reject the null hypothesis, H_o, the $F_{statistic}$ value must be absolutely greater than the $F_{critical}$ value found in the statistical tables for a 95 percent confidence level. Should any regression coefficients prove insignificant under this test, they will be considered for deletion in order to simplify the model. Care will be taken to account for multicollinearity, explanatory power held in common between two or more variables, before eliminating any variable from the model (11).

The criteria used to evaluate the predictive power of the model concerns a subjective test on the coefficient of multiple determination (R^2). This coefficient is calculated as part of the SPSS output and is equal to:

$$R^2 = \frac{\text{variation explained by regression}}{\text{total variation}}$$

An R^2 of .50 is described as a minimum level useful for management engineering program purposes and was used in this effort as a minimum, also (26:6-13).

Assumptions

1. Maintenance data is compiled accurately and within AF regulations.

2. Multiple linear regression techniques, with the underlying assumptions, are appropriate for constructing the model (1:1-17; 30:263-323).

3. Current corrosion man-hour totals represent that which would be required to maintain the F-4 fleet in adequate condition to perform its mission.

Limitations

The model developed will be a preliminary model for predicting future corrosion control man-hour expenditures for the air bases included in the sample. Inferences to an enlarged or similar population must be based on subjective evaluation of the respective situation. Additional research toward a finalized model should be performed when PACAFR 66-19 has been fully implemented and documentation difficulties have been overcome.

Chapter 3

ANALYSIS AND RESULTS

Introduction

It should be noted that the results of any analysis are only as valid as the data used. Predictions based on data collected from the AFM 66-1 system should be judged critically in the light of known inaccuracies in documentation. Since steps have been initiated to improve documentation procedures in PACAF, future predictive models based on such data should be quite reliable.

The analysis of PACAF corrosion man-hours required numerous computer runs in which particular variables were inserted and deleted in an effort to arrive at a model with the greatest explanatory power. What follows is an analysis of four computer runs which showed the most interaction between base-level corrosion man-hours and the selected predictor variables.

Analysis of First Regression

The first model regressed base-level corrosion control man-hours with the selected variables shown in Table 5. The results are tabulated in Table 6. X_{OS}, the number of months spent at Osan between CY 74 and CY 76 was

Table 5

Variables Used in the First Regression

Variables		
Dependent	Independent	Description
X_{13}		Total base-level CC man-hours
	X_{AG}	Aircraft age (yrs)
	X_T	Time since last PDM (months)
	X_{PDM}	Man-hours in last PDM
	X_{CR}	Man-hours in last contract CC
	X_{AF}	Aircraft airframe hours
	X_{C2}	Inspection man-hours
	X_{D1}	Dummy variable--F-4C
	X_{D2}	Dummy variable--F-4D
	X_{D3}	Dummy variable--F-4E
	X_{KU}	Months in Kunsan
	X_{OS}	Months in Osan
	X_{CL}	Months in Clark
	X_{KA}	Months in Kadena
	X_{TH}	Months in Thailand

Table 6

Results of the First Regression

Variable	Coefficient	Std Error	F-Statistic	Significance
X_{KA}	10.25509	1.05128	4.856	.95+
X_{D3}	144.79595	85.69602	2.855	.90+
X_{TH}	4.21500	.28710	4.045	.95+
X_{T}	2.98142	1.65717	3.237	.90+
X_{CR}	-0.01892	0.01246	2.306	.90-
X_{AG}	-14.63856	19.64837	0.555	None
X_{PDM}	-0.00327	0.00408	0.642	None
X_{AF}	-0.01111	.02361	0.221	None
X_{CL}	1.62550	2.50658	0.421	None
X_{KU}	2.64166	3.61800	0.533	None
X_{D5}	111.89124	144.11895	0.603	None
X_{D4}	61.84254	93.29672	0.439	None
X_{C2}	.34267	1.77012	0.037	None

CONSTANT TERM: 100.84490 R^2 = .61271 F-STATISTIC = 8.03175

DEGREES OF FREEDOM: UPPER: 13 LOWER: 66 STD ERROR: 90.86399

OVERALL REGRESSION SIGNIFICANT AT THE .001 LEVEL

the only variable unable to meet the regression program's minimum F-level to enter the equation. This model gave the highest R^2 of the many combinations tested. The statistical test of the significance of the overall regression (R^2) showed a .999 confidence that a linear relationship exists between C_{13}, the dependent variable representing total yearly base-level corrosion man-hours, and the selected independent variables shown in Table 5. Table 6 shows that not all of the independent variables are statistically significant in helping to explain variation in corrosion control man-hours. Thus, some refinements in this model were attempted with the following results.

Analysis of the Second Regression

Before any nonsignificant variables were deleted from the equation, dummy variables corresponding to current base of assignment were substituted for X_{KU}, X_{CL}, X_{OS}, X_{KA}, and X_{TH}, the variables representing the location of the aircraft between CY 74 and CY 76. This was done because historical record keeping could be eased if this substitution showed an acceptable R^2. When using regression analysis, tradeoffs must often be made between explanatory power and costs for obtaining data. The results of this model appear in Table 7.

X_{D5}, the dummy variable representing the F-4E MDS and X_{B2}, the dummy variable representing Kadena AB as the

Table 7

Results of the Second Regression

Variable	Coefficient	Std Error	F-Statistic	Significance
X_{D3}	148.83552	82.91756	3.222	.90+
X_{B1}	140.15576	35.08529	15.958	.9999+
X_{AG}	-16.22164	18.21521	0.793	None
X_{CR}	-0.02548	0.01173	4.721	.95+
X_{B3}	-91.75222	44.12392	4.324	.95+
X_{D4}	-75.67905	37.23832	4.130	.95+
X_{T}	2.63491	1.61014	2.678	.90-
X_{PDM}	-0.00442	0.00392	1.266	None
X_{C2}	0.94032	1.80337	0.272	None
X_{AF}	-0.00382	0.02273	0.028	None

CONSTANT TERM: 333.60061 $R^2 = .60352$ F-STATISTIC = 10.50296

DEGREES OF FREEDOM: UPPER: 10 LOWER: 69 STD ERROR: 89.91484

OVERALL REGRESSION SIGNIFICANT AT THE .001 LEVEL

current base of assignment, were not able to enter the equation due to failure to meet the minimum regression program F-level test. There was a small decrease in the explanatory power of the model, from .61271 to .60352. This decrease was considered a small tradeoff to make in return for simplifying the model. The new R^2 was also shown to be significant with a confidence in excess of 99.9%. Further simplification of the model was attempted by eliminating some of the independent variables shown to be insignificant in contributing to the explanatory power of the model. The results are described in the section which follows.

Analysis of the Third Regression

X_{AG}, X_{AF}, and X_{C2} were eliminated from the model because they were shown in Table 7 to be nonsignificant in explaining variation in base-level corrosion man-hours. X_{PDM}, man-hours in last PDM, was also shown to be nonsignificant but was allowed to remain in the model for the following reason. Since July 1976, the PDM package which is performed on F-4's in Tainan includes what was previously the midphase contract corrosion control package. Since some of the aircraft have had contract corrosion control last while others have had PDM last, it was believed that one should not be eliminated without the other. Technically,

X_T, time since last PDM or CCC, was not significant either; however, its F-statistic was very close to F-critical at a 90% level of confidence so a subjective determination was made to let it remain in the model.

The results of the third regression are shown in Table 8. Again X_{B2} could not meet the required F-level for admission to the model. The simplified model resulting from the third regression showed a further small decrease in explanatory power. The loss in R^2 of only 0.00665 was considered inconsequential when compared with the advantages gained by reducing the model by three variables. A final attempt was made to simplify the model still further in the fourth regression.

Analysis of the Fourth Regression

In this regression model, X_{PDM} and X_{CR} were eliminated. X_{CR}, man-hours in last contract corrosion control, has been a statistically significant variable up to this point and to delete it from the model requires a conscious decision on the part of the analyst. Had PDM man-hours been broken down into two categories, man-hours devoted to corrosion repair and man-hours devoted to other maintenance overhaul work (TCTOs, modifications, etc), the portion devoted to corrosion would correspond roughly to the man-hours spent in contract corrosion control. Under these circumstances, PDM man-hours, like CCC man-hours, may have

Table 8

Results of the Third Regression

Variable	Coefficient	Std Error	F-Statistic	Significance
X_{D3}	94.74612	48.72332	3.781	.90+
X_{B1}	127.78990	29.71944	18.489	.999+
X_{D4}	-89.29553	41.21869	4.693	.95+
X_{CR}	-0.02690	0.01197	5.046	.95+
X_{B3}	-87.37285	42.72811	4.181	.95+
X_{T}	2.91633	1.56222	3.485	.90+
X_{PDM}	-0.00481	0.00395	1.479	None
X_{D5}	19.32659	54.53795	0.126	None

CONSTANT TERM: 189.41722 R^2 = .59487 F-STATISTIC = 13.03147

DEGREES OF FREEDOM: UPPER: 8 LOWER: 71 STD ERROR: 89.60076

OVERALL REGRESSION SIGNIFICANT AT THE .001 LEVEL

proved to be statistically significant in explaining base-level corrosion man-hours. In any case, man-hours spent on corrosion control at a contractor's facility are difficult to document and track accurately. Therefore, another judgement was made to eliminate X_{PDM} and X_{CR} from the analysis to determine what effect this action would have on the explanatory ability of the model. The results of this fourth regression appear in Table 9. X_{D5} once again did not enter the model. The R^2 value suffered a loss of about 4 percent. This model represents a simple predictive equation which, based on the available data, would be useful to explain approximately 55 percent of the variation in base-level corrosion maintenance man-hours. This model, run with a variable representing the corrosion index instead of the dummy variables corresponding to the base of assignment, was not as powerful in explaining variation.

Multicollinearity

In an MLR model involving two or more independent variables, inner-correlation may exist between and among variables. The effect of such inner-correlation is to reduce the ability to account for the explanatory power as owing to the presence of particular independent variables in the model. This phenomenon is called multicollinearity (11). One method to observe the extent of the multicollinearity problem as it may exist in a regression

Table 9

Results of the Fourth Regression

Variable	Coefficient	Std Error	F-Statistic	Significance
X_{D3}	102.54949	48.58901	4.454	.95+
X_{B1}	129.13076	46.35076	7.761	.99+
X_{D4}	-97.95907	42.00776	5.438	.95+
X_{B3}	-81.01608	44.01979	3.387	.90+
X_T	2.39477	1.59866	2.244	.90-
X_{B2}	15.53650	54.48587	0.081	None

CONSTANT TERM: 138.28030 R^2 = .55643 F-STATISTIC = 15.26227

DEGREES OF FREEDOM: UPPER: 6 LOWER: 73 STD ERROR: 92.46190

OVERALL REGRESSION SIGNIFICANT AT THE .001 LEVEL

model is to examine the correlation matrix of the independent variables. Table 10 shows this matrix, called the Pearson correlation matrix, the output of the Pearson Corr subprogram. Each entry in the matrix is the Pearson correlation coefficient (product-moment), r, and indicates the strength of the linear relationship between each pair of variables. "Its usefulness derives from the fact that r^2 is a measure of the proportion of variance in one variable "explained" by the other [16:279]."

From Table 10, it can be seen that the only two variables which exhibit a strong linear relationship with each other are X_{PDM}, PDM man-hours, and X_{CR}, contract corrosion control man-hours. This can be expected because PDM includes the same corrosion maintenance package previously performed during contract corrosion control as mentioned previously. Since contract corrosion control no longer exists as a separate entity, this problem will not hinder future corrosion prediction models.

Standard Error of the Estimate

The principal objective of most regression analysis applications is the derivation of a mathematical expression with which to predict values for a dependent variable for specified values of the independent variables. The prediction of these values of the dependent variable is

Table 10

Pearson Correlation Matrix for Selected Variables

Variable	X_{C2}	X_{AG}	X_{AF}	X_T	X_{PDM}	X_{CR}
X_{C2}	1.00	-.2284	-.1182	-.0704	.3209	-.1634
X_{AG}		1.00	.3648	.0516	-.3604	.1064
X_{AF}			1.00	-.0276	.0432	-.1028
X_T				1.00	-.0956	.1051
X_{PDM}					1.00	-.8168
X_{CR}						1.00

subject to two types of errors. The first occurs when a less than perfect relationship exists among the variables. This type of error would likely exist even if all the universe data were considered. Its order of magnitude is suggested by the value of the coefficient of determination, R^2.

The second source of prediction error is sampling, for the estimators, X_i, are subject to sampling error (4:540). From Tables 6, 7, 8, and 9, it can be seen that previous concern about the accuracy of some of the data has been justified. All four regression models result in relatively high standard errors. For this reason, the utility of these models for the purpose of prediction is doubtful. Appendix C gives a better indication of the extent of this problem. It tabulates predicted and actual values for the dependent variable along with providing a scattergram for each regression. The scattergram shows the amount of dispersion which the actual values of the dependent variable have about the regression line.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

Introduction

The objectives of this research were to: (1) establish whether a linear relationship exists between base-level corrosion control man-hours and selected independent variables; (2) construct a model which could be used to predict yearly base-level maintenance man-hours devoted to corrosion control; and (3) identify the variables whose net or marginal contributions to the explanatory power of the model were significant. This final chapter discusses how successful the analysis was in meeting the objectives and makes recommendations for future research in this area.

Meeting the Objectives

Within the confines of the data which were available, the objectives of this research were attained. The first objective was to show if a linear relationship exists between the dependent variable, base-level corrosion control man-hours, and the independent variables selected for the analysis. The hypothesis tested to meet this objective was:

H_o: $R^2 = 0$ which is equivalent to

$B_1 = B_2 = B_3 = . . . = B_i = 0$

H_1: $R^2 \neq 0$ which is equivalent to

at least one $B_i \neq 0$.

In Chapter 3, it was shown that the F-statistic was great enough in each regression to express with 99.9 percent confidence that the null hypothesis can be rejected and the conclusion drawn that a statistically significant linear relationship exists between base-level corrosion man-hours and selected predictor variables used in the regression.

The second objective was to construct a model which could be useful in predicting base-level corrosion maintenance man-hours. Numerous models were analyzed with R^2, a measure of the explanatory power of the model, between .55 and .61 in most cases. While the derived values of R^2 are not as high as may be desired, they exceed the minimum value specified in AFM 25-5 for use in the Air Force Management Engineering Program. While the models discussed in Chapter 3 could possibly be used to predict expected man-hour expenditures in F-4 corrosion maintenance at the four PACAF bases studied, they would be better used as preliminary models only, with refinements being made in the future when current attempts to bring the corrosion problem under control are fruitful.

The final objective involved identifying the predictor variables whose net or marginal contributions to

the explanatory power of the model have been shown to be statistically significant. The hypothesis test to show significance was:

$$H_o: B_i = 0$$
$$H_1: B_i \neq 0.$$

A brief discussion of each significant variable follows.

<u>Base</u>. Two of the dummy variables representing the various air bases studied proved to be significant. Clark AB, P.I. was chosen as the base variable and the coefficients of X_{B1}, X_{B2}, and X_{B3} represent man-hours above or below that experienced at Clark by virture of that aircraft being assigned elsewhere. The results of the analysis show that we are more than 95 percent confident that the net or marginal contribution to explained variation of X_{B1}, Kadena as a base of assignment, is significantly different than zero. The coefficient associated with X_{B1}, 129.13076, means that the expected value of yearly corrosion man-hours for any F-4 assigned to Kadena is about 129 man-hours higher than at Clark. By the same reasoning, corrosion man-hours at Osan AB, Korea, is expected to be about 81 man-hours per year less than that expended at Clark, although we are only 90 percent confident of its significance. The coefficient of X_{B2} was shown to be not significantly different than zero; therefore, it can be concluded that corrosion man-hours are approximately the same at Kunsan

and Clark. The corrosion severity indices for the four PACAF bases under study show Kunsan and Kadena as having the most severe corrosion environment and Osan the least severe which tend to support our findings.

Mission design series. X_{D3} and X_{D4}, dummy variables representing the F-4C and F-4D MDS, were found to have net or marginal contributions significantly different from zero at a 95 percent confidence level. The base-level for this series of dummy variables was the RF-4C. An F-4C, by virtue of its MDS and regardless of any other factor, would be expected to require 102.54949 more man-hours of corrosion maintenance per year than the RF-4C. The F-4D should require 97.95907 man-hours less than the RF-4C for corrosion maintenance. X_{D5}, the F-4E MDS, was shown to have an insignificant net or marginal contribution to explained variation, and therefore, is believed to require approximately the same number of man-hours per year as the RF-4C at base-level for corrosion maintenance.

Man-hours in contract corrosion control. X_{CR} was shown to have a significant net or marginal contribution to the explanatory power of the model at the 95 percent level of confidence. The value of the coefficient of this variable was -0.02690 which means that for an additional 1000

man-hours devoted to corrosion maintenance and prevention at the contractor's facility, about 27 man-hours a year are saved at base level.

<u>Time since last PDM</u>. X_T, the time in months since the last major corrosion rework at either PDM or CCC, was shown to be significant at the 90 percent level in 2 of the 4 regressions. An analysis of its coefficient suggests that for each month that passes since major corrosion rework, yearly base-level corrosion man-hours increases approximately 3 man-hours.

These predictor variables have been identified by this study to be significant in predicting corrosion experience at the base level. Future study in this area should include an analysis of their effects in any proposed model.

Conclusions

The degree of confidence in the results of this study must be tempered with the realization that some of the data may be imprecise due to deficiencies in methods of documentation and collection. Nevertheless, the conclusion can be drawn that multiple regression analysis is a proper tool to use in constructing predictive models of the corrosion experienced at the base-level. Predictive models like these are useful to the manager in forecasting future needs in such areas as facilities, training, and

manning. Failure to manage these areas effectively has resulted in a serious corrosion problem in the PACAF F-4 fleet. With the implementation of PACAFR 66-19, more precise models can be formulated in the future to help manage the corrosion prevention and control effort more effectively.

Recommendations for Further Research

After the problems of data validity have been overcome, additional research in the area of corrosion prediction will likely yield fruitful results. A follow-on study similar to this one should be accomplished by 1979 using data from 1978. By this time frame, much of the imprecision in documentation should have been overcome. In addition, the variables mentioned in Chapter 2, which were not part of this analysis but which appear to be useful factors related to corrosion man-hours, could be incorporated into the analysis. These efforts should result in a regression model which fits the data with an R^2 much better than .55 or .61.

Should the additional efforts fail to find a model of sufficient explanatory power, some nonlinear form of regression should be attempted. Various subprograms for nonlinear regression are readily available and can provide the analyst with the necessary tools for developing the appropriate predictive model.

APPENDICES

APPENDIX A

COMPUTER PROGRAM

```
001##S,R(SL) :,8,16;;,16
010$:IDENT:WP1191,AFIT/SLG HARRINGTON&-TEOMY
025$:SELECT:SPSS/BIGSPSS
1010RUN NAME;THESIS,REGRESSION
1020VARIABLE LIST;BASE,DEGEM,YEAR,KU,OS,CL,KA,TH,T,PDM,CR
1025;AF,C1,C2,C3
1030VAR LABELS;BASE,BASE/
1035;DEGEM,TYPE/
1040;YEAR,AGE/
1042;KU,KUNSAN/
1045;OS,OSAN/
1046;CL,CLARK/
1047;KA,KADENA/
1048;TH,THILAND/
1049;T,TIME SINCE LAST PDM/
1050;PDM,MHRS IN PDM/
1051;CR,MHRS IN COR. CONT./
1052;AF,AIRFRAME HOURS/
1053;C1,MHRS IN CORR 170+677/
1054;C2,INSPECTION TIME 04141/
1055;C3,MHRS TOTAL
1057INPUT FORMAT;FREEFIELD
1060INPUT MEDIUM;CARD
1070N OF CASES;80
1075COMPUTE;C13=C1+C3
1080COMPUTE;C123=C1+C2+C3
1085COMPUTE;AG=YEAR-1
1090IF;(DEGEM EQ 3)D3=1
1100IF;(DEGEM EQ 4)D4=1
1110IF;(DEGEM EQ 5)D5=1
1112IF;(BASE EQ 1)B1=1
1113IF;(BASE EQ 2)B2=1
1114IF;(BASE EQ 3)B3=1
1120REGRESSION;VARIABLES=D3,D4,D5,KU,OS,CL,KA,TH,T,PDM,CR
1121;AF,C1,C2,C13,B1,B2,B3,AG/
1140;REGRESSION=C13 WITH D3,D4,D5,B1,B2,B3,T
1141;C2,AF(1) RESID=0
1150STATISTICS;2,4,6
1160READ INPUT DATA
1170$:SELECTA:TH12
1190FINISH
9999$:ENDJOB
```

APPENDIX B

INPUT DATA FILE

010	2	4	11	27	0	9	0	0	15	9897	0	3413	9.7	21.0	28.5
020	2	4	11	27	0	9	0	0	23	9720	0	3445	.5	22.0	69.4
030	2	4	11	27	0	9	0	0	14	9624	0	3465	2.3	19.1	76.4
040	2	4	11	27	0	9	0	0	17	9560	0	3468	1.9	10.4	70.4
050	2	4	11	27	0	9	0	0	9	11357	0	3573	.5	10.3	83.1
060	2	4	11	27	0	9	0	0	10	16579	0	2604	18.2	27.3	114.2
070	2	4	11	27	0	9	0	0	11	9508	0	3675	2.3	10.3	69.1
080	2	4	11	27	0	9	0	0	19	9762	0	2808	.8	27.5	116.0
090	2	4	11	19	0	1	0	16	26	10830	0	3399	8.9	13.9	118.7
100	2	4	11	19	0	1	0	16	30	9938	0	3227	6.0	34.9	97.8
110	2	4	11	19	0	0	0	17	12	9864	0	4267	3.5	18.5	124.7
120	2	4	11	19	0	0	0	17	15	9549	0	3773	17.4	28.6	98.6
130	2	4	11	19	0	0	0	17	16	9637	0	3337	6.8	25.5	142.5
140	2	4	11	20	0	0	0	16	6	10148	0	3916	1.5	14.2	25.5
150	2	4	11	20	0	0	0	16	25	0	3607	3802	12.1	13.9	95.9
160	2	4	11	27	0	9	0	0	24	10667	0	2295	12.4	14.3	109.5
170	3	5	11	1	27	2	0	6	8	0	4435	2683	2.2	33.1	52.5
180	3	5	10	1	27	2	0	6	13	16857	0	4044	13.9	28.6	181.8
190	3	5	10	1	27	2	0	6	9	9478	0	3790	.5	29.7	80.0
200	3	5	10	1	27	2	0	6	15	16924	0	2702	9.8	32.8	80.2
210	3	5	9	1	27	2	0	6	16	11957	0	2744	5.3	28.7	53.8
220	3	5	8	1	27	2	0	6	26	12274	0	2313	2.5	5.2	104.1
230	3	5	8	1	27	2	0	6	18	12428	0	2077	1.0	37.0	64.7
240	1	4	11	18	0	0	6	12	21	0	4357	3061	13.0	5.8	136.3
250	1	4	11	9	0	14	13	0	20	0	2398	3206	12.3	9.2	107.2
260	1	4	11	0	0	0	13	23	18	8991	0	3570	42.9	6.9	315.3
270	1	4	11	23	0	0	13	0	12	0	2694	3171	8.5	8.4	124.6
280	1	4	11	14	0	0	6	16	6	0	4288	2790	2.0	12.4	85.6
290	1	4	11	0	0	17	13	6	19	9526	0	3868	14.9	6.1	127.1
300	1	4	11	14	0	9	13	0	28	0	4321	3056	44.7	5.8	114
310	1	4	11	14	0	9	13	0	18	12484	0	3526	83.3	4.7	139.2
320	1	4	11	17	0	0	13	6	17	0	2341	2588	11.2	3.0	161.5
330	1	4	11	6	0	0	13	17	11	9970	0	3111	121.7	4.3	212.2
340	1	4	11	14	0	9	13	0	31	0	3997	2996	66.0	9.7	79.8
350	1	4	11	0	0	12	13	11	7	0	4262	3031	34.0	7.2	204.3
360	1	4	11	0	0	0	13	23	6	7053	0	2742	37.4	5.4	103.6
370	1	4	11	0	0	0	13	23	9	9851	0	2771	34.4	8.4	159.8
380	1	4	11	0	0	6	13	17	27	0	4159	3820	52.8	8.7	147.6
390	1	4	11	14	0	2	13	7	31	9577	0	3731	167.0	2.3	144.8
400	1	3	14	0	0	0	36	0	20	6355	0	3448	311.5	10.4	154.1
410	1	3	14	0	0	0	36	0	20	0	2902	2869	58.8	10.6	218.8
420	1	3	14	0	0	0	36	0	9	0	5507	3529	72.3	7.7	221.1
430	1	3	14	0	0	0	36	0	24	6114	0	3738	387.6	10.7	190.7
440	1	3	14	0	0	0	36	0	30	0	3843	3247	35.4	11.2	355.2
450	1	3	14	0	0	0	36	0	11	3109	0	3486	79.3	13.8	169.9
460	1	3	14	0	0	0	36	0	9	6704	0	3267	255.2	18.9	187.3
470	1	3	14	0	0	0	36	0	15	4364	0	2976	557.7	11.3	181.7
480	1	3	13	0	0	0	36	0	12	4096	0	3083	45.1	13.2	276.1

490	1	3	13	0	0	0	36	0	23	6822	0	2960	147.0	10.4	209.1
500	1	4	12	6	0	0	18	12	16	0	2461	2892	10.0	1.7	74.8
510	1	4	12	6	0	0	18	12	20	9909	0	3416	19.8	6.5	230.2
520	1	4	12	6	0	0	18	12	7	10517	0	3490	48.8	15.6	163.2
530	1	4	12	6	0	0	18	12	11	9606	0	3445	85.3	3.9	254.1
540	1	4	11	0	0	0	18	18	13	0	2285	4023	43.6	6.9	201.7
550	1	4	11	6	0	0	18	12	16	0	2850	3174	128.9	6.3	287.4
560	1	4	11	0	0	0	18	18	17	9197	0	3566	47.9	11.9	196.7
570	1	4	11	0	0	0	18	18	11	9981	0	3791	29.7	2.3	205.1
580	1	4	11	6	0	0	18	12	10	9926	0	3091	33.5	5.1	138.5
590	1	4	11	0	0	0	18	18	7	10104	0	2913	13.9	5.7	120.2
600	1	4	11	0	0	0	18	18	23	0	3115	3091	14.2	9.5	163.6
610	1	4	11	6	0	0	18	12	14	9330	0	3091	22.0	23.9	227.1
620	1	4	11	0	0	0	18	18	14	0	2319	4097	23.7	5.9	122.8
630	1	1	11	0	0	0	36	0	13	11394	0	4320	38.6	10.0	204.8
640	1	1	11	0	0	0	36	0	11	10233	0	4158	97.9	6.3	183.5
650	1	1	11	0	0	0	36	0	13	10053	0	3096	97.3	14.2	408.7
660	1	1	11	0	0	0	36	0	10	12988	0	2944	7.2	5.2	41.7
670	1	1	9	0	0	0	36	0	7	0	3562	2703	48.2	7.2	209.4
680	1	1	9	0	0	0	36	0	16	5143	0	2870	219.5	5.2	215.3
690	4	5	11	0	0	13	0	23	8	0	4506	3219	13.9	30.1	101.5
700	4	5	10	0	0	13	0	23	15	16875	0	4464	12.9	24.2	64.3
710	4	5	10	0	0	13	0	23	11	0	2352	3323	13.0	18.6	81.1
720	4	5	10	0	0	13	0	23	18	18034	0	4377	18.9	14.2	83.0
730	4	5	10	0	0	13	0	23	12	16769	0	2879	10.0	18.0	102.1
740	4	5	10	0	0	13	0	23	9	17031	0	3604	19.2	17.0	69.3
750	4	5	9	0	0	13	0	23	11	12242	0	3464	18.3	7.2	136.4
760	4	5	9	0	0	13	0	23	18	12219	0	2731	47.2	28.9	185.3
770	4	5	9	0	0	13	0	23	6	5335	0	2706	9.0	17.6	229.8
780	4	5	8	0	0	13	0	23	29	14603	0	2319	5.3	10.1	298.9
790	4	5	8	0	0	13	0	23	17	0	4553	2465	23.3	14.8	279.3
800	4	5	6	0	0	13	0	23	11	16827	0	1092	8.6	19.0	223.4

APPENDIX C

COMPARISON OF OBSERVED VS PREDICTED VALUES OF THE DEPENDENT VARIABLE, PLOT OF STANDARDIZED RESIDUALS, AND SCATTERGRAMS OF THE FOUR REGRESSIONS

REGRESSION #1

DEPENDENT VARIABLE C13 FROM VARIABLE LIST 1
REGRESSION LIST 1

SEQNUM	OBSERVED C13	PREDICTED C13	RESIDUAL
1	149.3000	124.1075	25.19246
2	119.5000	177.9358	-58.43576
3	358.2000	233.5301	124.6699
4	133.1000	162.8245	-29.72449
5	87.60000	92.25783	-4.657831
6	142.0000	187.1557	-45.15570
7	158.7000	170.9827	-12.28270
8	222.5000	176.5118	45.98818
9	172.7000	198.4781	-25.77807
10	333.9000	204.2279	129.6721
11	145.8000	188.0687	-42.26870
12	238.3000	124.5050	113.7950
13	141.0000	212.7753	-71.77534
14	194.2000	213.2768	-19.07677
15	200.4000	193.3671	7.032939
16	311.8000	239.8017	71.99832
17	465.6000	428.6264	36.97357
18	277.6000	400.9958	-123.3958
19	293.4000	310.5021	-17.10207
20	578.3000	438.2208	140.0792
21	390.6000	409.0104	-18.41036
22	249.2000	413.1500	-163.9500
23	442.5000	399.6134	42.88655
24	739.4000	425.7819	313.6181
25	321.2000	431.8148	-110.6148
26	356.1000	456.1043	-100.0043
27	38.20000	83.89280	-45.69280
28	69.90000	108.3101	-38.41011
29	78.70000	80.57524	-1.875244
30	72.30000	86.71419	-14.41419
31	83.60000	55.78629	27.81371
32	132.4000	58.28493	74.11507
33	71.40000	66.66154	4.738462
34	116.8000	105.2093	11.59073
35	127.6000	144.6631	-17.06308
36	103.8000	168.4125	-64.61250
37	128.2000	100.6035	27.59647
38	116.0000	119.5274	-3.527385
39	149.3000	126.0030	23.29699
40	27.00000	82.63941	-55.63941
41	108.0000	105.3801	2.619903
42	121.9000	118.3337	3.566263
43	84.80000	222.2715	-137.4715
44	250.0000	244.1872	5.812845
45	212.0000	205.7369	6.263134

REGRESSION #1

THESIS.REGRESSION

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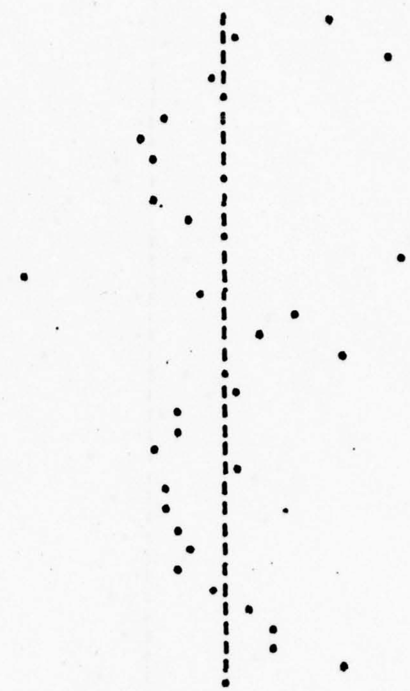
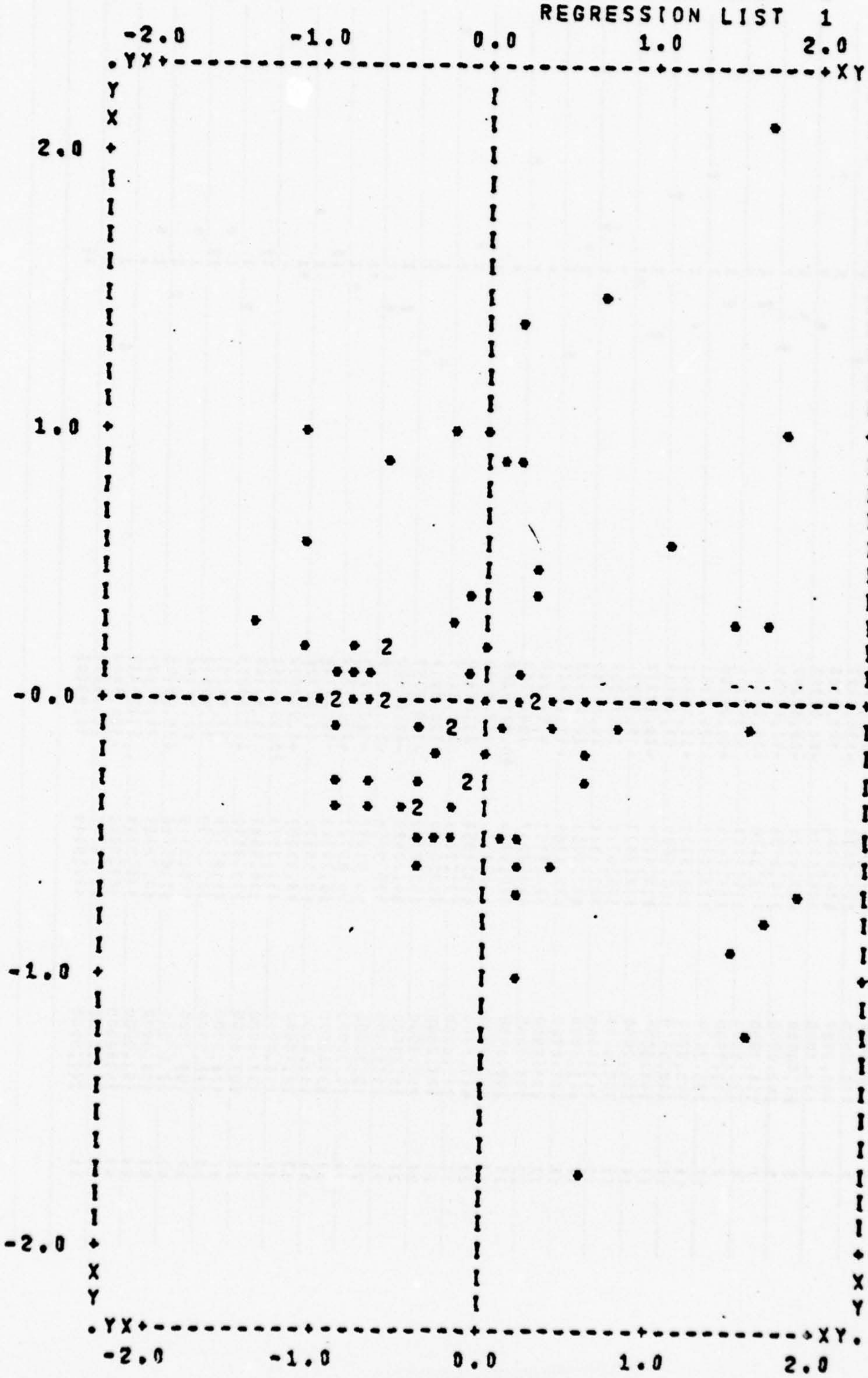
46	339.4000	217.1319	122.2681
47	245.3000	229.9519	15.34814
48	416.3000	227.9926	188.3074
49	244.6000	261.8334	-17.23339
50	234.8000	235.5910	-0.7910346
51	172.0000	232.0871	-60.08715
52	134.1000	234.1842	-100.0842
53	177.8000	255.3070	-77.50696
54	249.1000	252.4038	-3.303826
55	146.5000	231.1251	-84.62508
56	243.4000	280.5746	-37.17464
57	281.4000	278.9400	2.460038
58	506.0000	299.9979	206.0021
59	48.90000	280.0610	-231.1610
60	257.6000	278.8251	-21.22509
61	434.8000	353.7005	81.09948
62	54.70000	18.99897	35.70103
63	195.7000	60.68180	135.0181
64	80.50000	76.08242	4.417577
65	90.00000	82.77533	7.224674
66	59.10000	114.7643	-55.66434
67	106.6000	154.9164	-48.31644
68	65.70000	144.0007	-78.30067
69	115.4000	97.56603	17.83397
70	77.20000	147.3055	-70.10552
71	94.10000	156.8102	-62.71025
72	101.9000	150.0001	-48.10008
73	112.1000	154.1936	-42.09361
74	89.00000	135.9948	-46.99482
75	154.7000	170.4521	-15.75214
76	232.5000	206.9774	25.52264
77	238.8000	190.1146	48.68544
78	304.2000	244.7519	59.44814
79	302.6000	170.5597	132.0403
80	232.0000	229.7741	2.225877



DEPENDENT VARIABLE C13 VARIABLE LIST 1
REGRESSION LIST 1

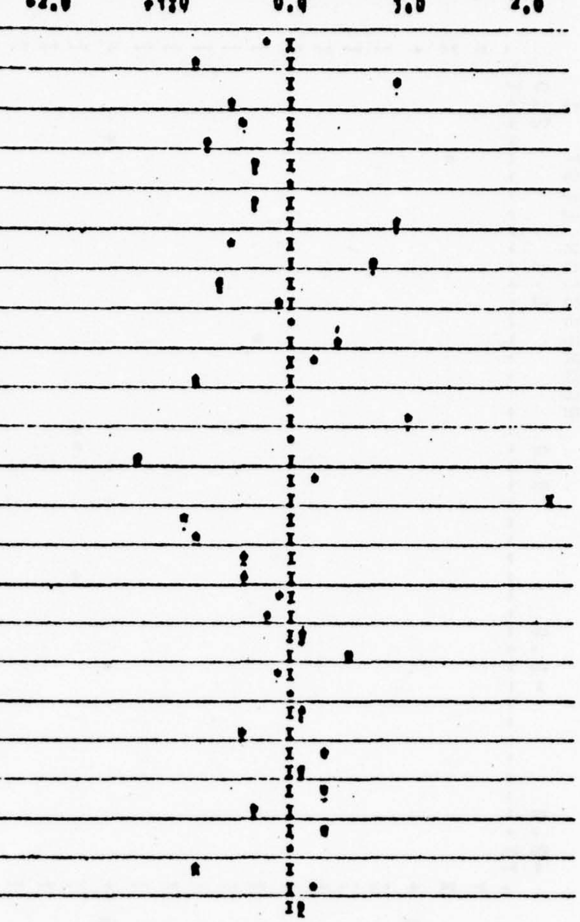


REGRESSION #2

DEPENDENT VARIABLE C13 FROM VARIABLE LIST 1
REGRESSION LIST 1

SEQNUM	OBSERVED C13	PREDICTED C13	RESIDUAL
1	149.3000	173.9463	-24.64630
2	119.5000	223.8627	-104.3627
3	358.2000	236.4294	121.7706
4	133.1000	194.6238	-61.52385
5	87.60000	143.4225	-55.82247
6	142.0000	234.8106	-92.81059
7	154.7000	193.3270	-38.62696
8	222.5000	219.1148	3.385240
9	172.7000	213.9424	-41.24240
10	333.9000	212.9717	120.9283
11	165.8000	213.3827	-47.58267
12	238.3000	140.9089	97.39109
13	141.0000	215.1227	-74.12272
14	198.2000	213.3823	-15.18232
15	200.4000	194.6258	5.774204
16	311.8000	263.1548	48.64519
17	465.6000	432.9463	32.65373
18	277.6000	389.4768	-111.8768
19	393.4000	388.8761	4.523884
20	578.3000	443.7237	134.5763
21	390.6000	390.9718	-0.3718289
22	309.2000	426.6174	-117.4174
23	442.5000	411.1051	31.39490
24	739.4000	431.2819	308.1181
25	321.2000	442.0819	-120.8819
26	356.1000	456.8759	-100.7759
27	38.20000	98.22690	-60.02690
28	69.90000	120.9058	-51.00579
29	78.70000	94.81211	-16.11211
30	72.30000	94.80722	-22.50722
31	83.60000	65.29744	18.30256
32	132.4000	64.56274	67.83726
33	91.40000	98.34207	-6.942072
34	118.8000	117.8187	0.9813352
35	127.6000	116.4683	11.13169
36	103.8000	151.3510	-47.55095
37	128.2000	84.85269	43.34731
38	116.0000	105.5539	10.44610
39	149.3000	106.5318	42.76816
40	27.00000	65.08746	-38.08746
41	108.0000	68.22169	39.77831
42	121.9000	116.5144	5.385617
43	88.80000	189.6442	-100.8442
44	250.0000	221.6365	28.36348
45	212.0000	192.9719	19.02809

PLOT OF STANDARDIZED RESIDUAL



REGRESSION #2

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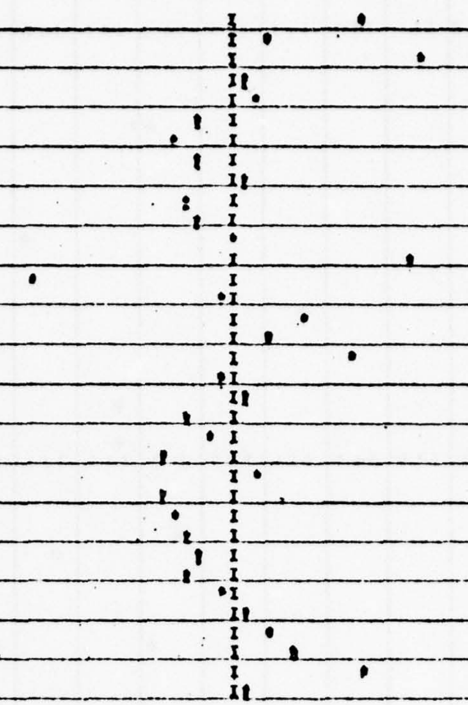
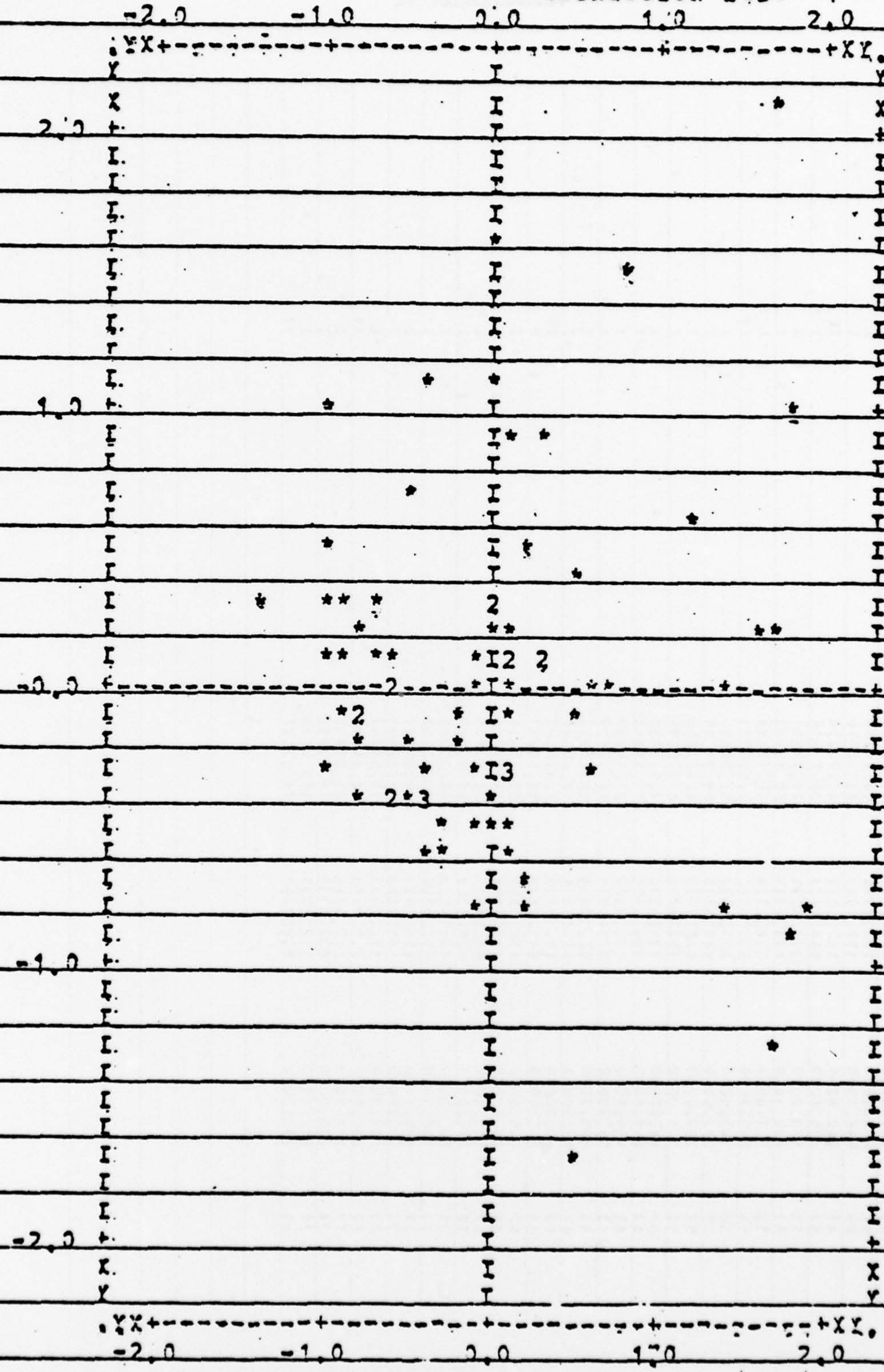
46	339.4000	176.7046	162.6954
47	245.3000	203.0114	42.28857
48	416.3000	199.2030	217.0970
49	244.6000	237.6018	6.998230
50	234.8000	208.4412	26.35878
51	172.0000	211.3598	-39.35981
52	134.1000	203.9117	-69.81168
53	177.8000	214.2224	-36.42244
54	249.1000	242.2092	6.890771
55	146.5000	203.5570	-57.05696
56	243.4000	288.3710	-44.97104
57	281.4000	285.3679	-3.967946
58	506.0000	302.9206	203.0794
59	48.90000	274.1730	-225.2730
60	257.6000	268.1185	-10.51855
61	434.8000	357.3509	77.44910
62	54.70000	8.591912	46.10809
63	195.7000	67.10643	128.5936
64	80.50000	91.15578	-10.65578
65	90.00000	81.15949	8.840509
66	59.10000	117.9332	-58.83317
67	106.6000	138.6542	-32.05416
68	65.70000	147.6991	-81.99905
69	115.4000	93.66550	21.73450
70	77.20000	159.3062	-82.10615
71	94.10000	161.4570	-67.35705
72	101.9000	152.0224	-50.12242
73	112.1000	151.0981	-38.99812
74	89.00000	138.3248	-49.32485
75	160.7000	172.2833	-11.58332
76	232.5000	214.0360	18.46395
77	238.8000	203.2850	35.51499
78	204.2000	133.6115	70.58852
79	302.6000	153.3625	149.2375
80	232.0000	[illegible]	[illegible]



DEPENDENT VARIABLE C13 VARIABLE LIST 1

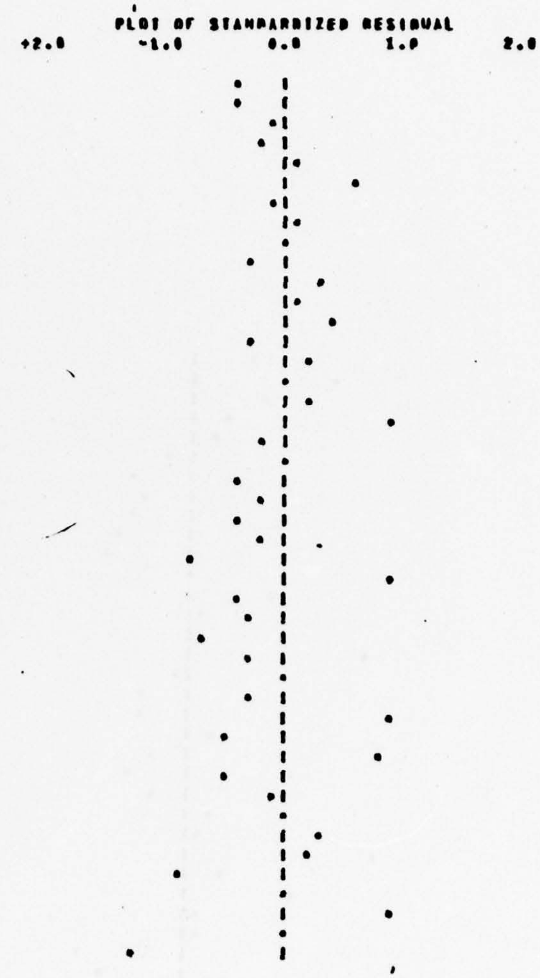
REGRESSION LIST 1



REGRESSION #3

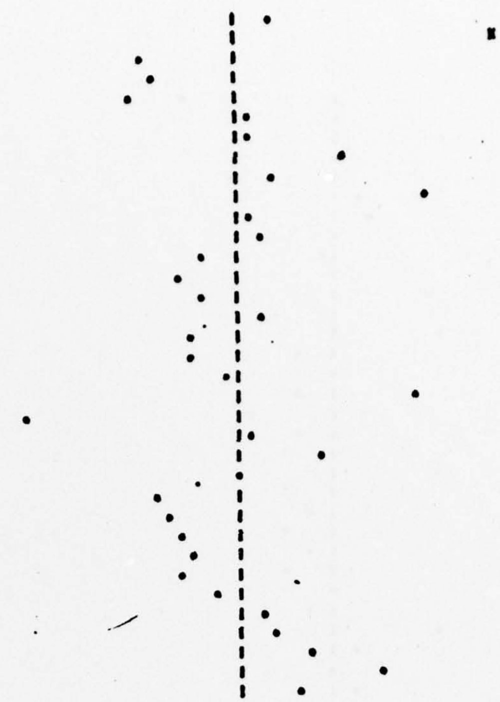
DEPENDENT VARIABLE C13 FROM VARIABLE LIST 1
REGRESSION LIST 1

SEQNUM	OBSERVED C13	PREDICTED C13	RESIDUAL
1	38.20000	96.28568	-58.08568
2	69.90000	120.4673	-50.56729
3	78.70000	94.60182	-15.90182
4	72.30000	103.7385	-31.43851
5	83.60000	71.76855	11.83145
6	132.4000	49.57950	82.82050
7	71.40000	86.49051	-15.09051
8	116.8000	108.6000	8.199945
9	127.6000	123.8798	3.720172
10	103.8000	139.8336	-36.03356
11	128.2000	87.69513	40.50487
12	116.0000	97.95873	18.04127
13	149.3000	108.4520	40.84801
14	27.00000	68.83197	-41.83197
15	108.0000	76.00591	31.99409
16	121.9000	118.8308	3.069196
17	54.70000	25.40523	29.29477
18	195.7000	78.24125	117.4588
19	80.50000	102.0513	-21.55134
20	90.00000	83.75180	6.248199
21	59.10000	110.5474	-51.44750
22	106.6000	138.1869	-31.58689
23	65.70000	114.1159	-48.41586
24	149.3000	171.9563	-22.65635
25	119.5000	221.7348	-102.2348
26	358.7000	237.1803	121.5197
27	133.1000	190.4421	-57.34212
28	87.60000	130.0674	-42.46737
29	142.0000	237.5245	-95.52453
30	158.7000	193.3390	-34.63903
31	222.5000	220.3873	2.112743
32	172.7000	214.5191	-41.81907
33	333.9000	212.0593	121.8407
34	145.0000	210.0033	-65.00325
35	238.3000	133.6831	104.6169
36	141.0000	211.5014	-70.50145
37	194.2000	206.7987	-12.59873
38	200.4000	194.7803	5.619688
39	311.8000	272.2753	39.52466
40	465.6000	439.7275	25.87253
41	277.6000	392.2195	-114.6195
42	293.4000	290.0685	3.331462
43	578.3000	452.5514	125.7486
44	390.6000	396.0710	-5.470992
45	249.2000	429.0068	-179.8068

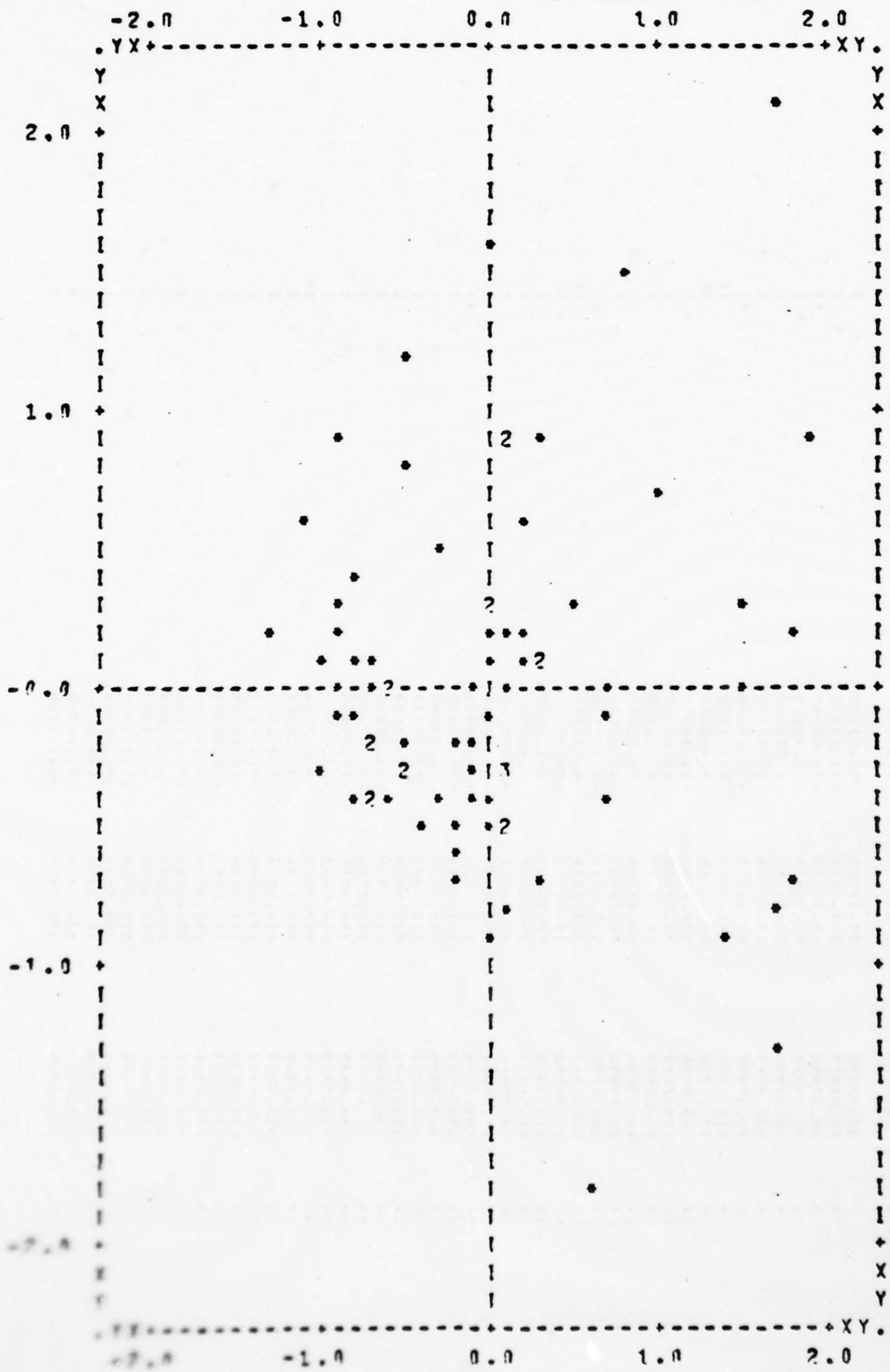


REGRESSION #3

46	442.5000	405.9700	34.53005
47	739.4000	434.7179	304.6922
48	321.2400	427.2972	-106.0572
49	356.1000	446.2313	-90.13131
50	84.80000	208.3749	-123.5749
51	250.0000	238.5918	11.40816
52	212.0000	197.7642	14.23582
53	339.4000	213.8093	125.5907
54	245.3000	204.3601	40.93993
55	416.3000	197.9112	218.3888
56	244.6000	233.2736	11.32643
57	234.8000	212.0064	22.79360
58	172.0000	209.3545	-37.35449
59	134.1000	199.7497	-65.64973
60	177.8000	211.1974	-33.39737
61	249.1000	223.8852	25.21484
62	146.5000	206.3418	-59.84185
63	243.4000	300.3414	-56.94143
64	281.4000	300.0984	-18.69840
65	586.0000	386.7884	199.2116
66	48.90000	283.9291	-235.0291
67	257.6000	241.8078	15.79221
68	434.8000	339.1429	95.65715
69	115.4000	110.8683	4.531684
70	77.20000	171.3602	-94.16023
71	94.10000	177.5574	-83.45741
72	101.9000	174.5372	-72.63719
73	112.1000	163.1208	-51.02083
74	89.00000	153.1122	-64.11224
75	154.7000	181.9686	-27.26860
76	232.5000	202.4935	30.00650
77	238.8000	208.5932	30.20684
78	304.2000	223.1118	81.08820
79	302.6000	135.8511	166.7489
80	232.0000	159.9257	72.07434



DEPENDENT VARIABLE C13 VARIABLE LIST 1
REGRESSION LIST 1

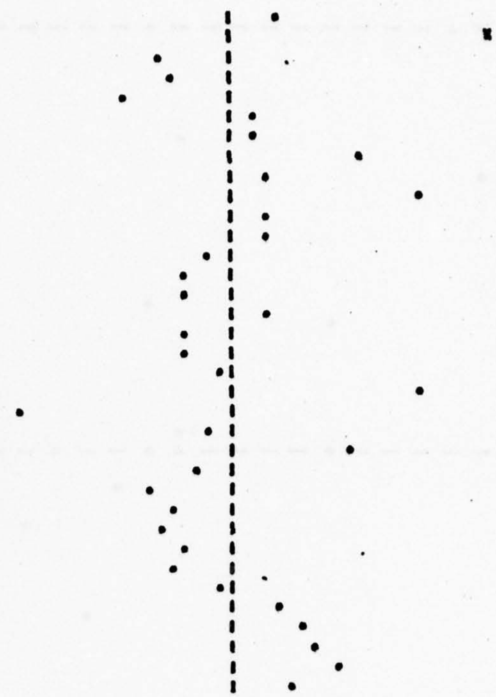


REGRESSION #4

DEPENDENT VARIABLE C13 FROM VARIABLE LIST 1
REGRESSION LIST 1

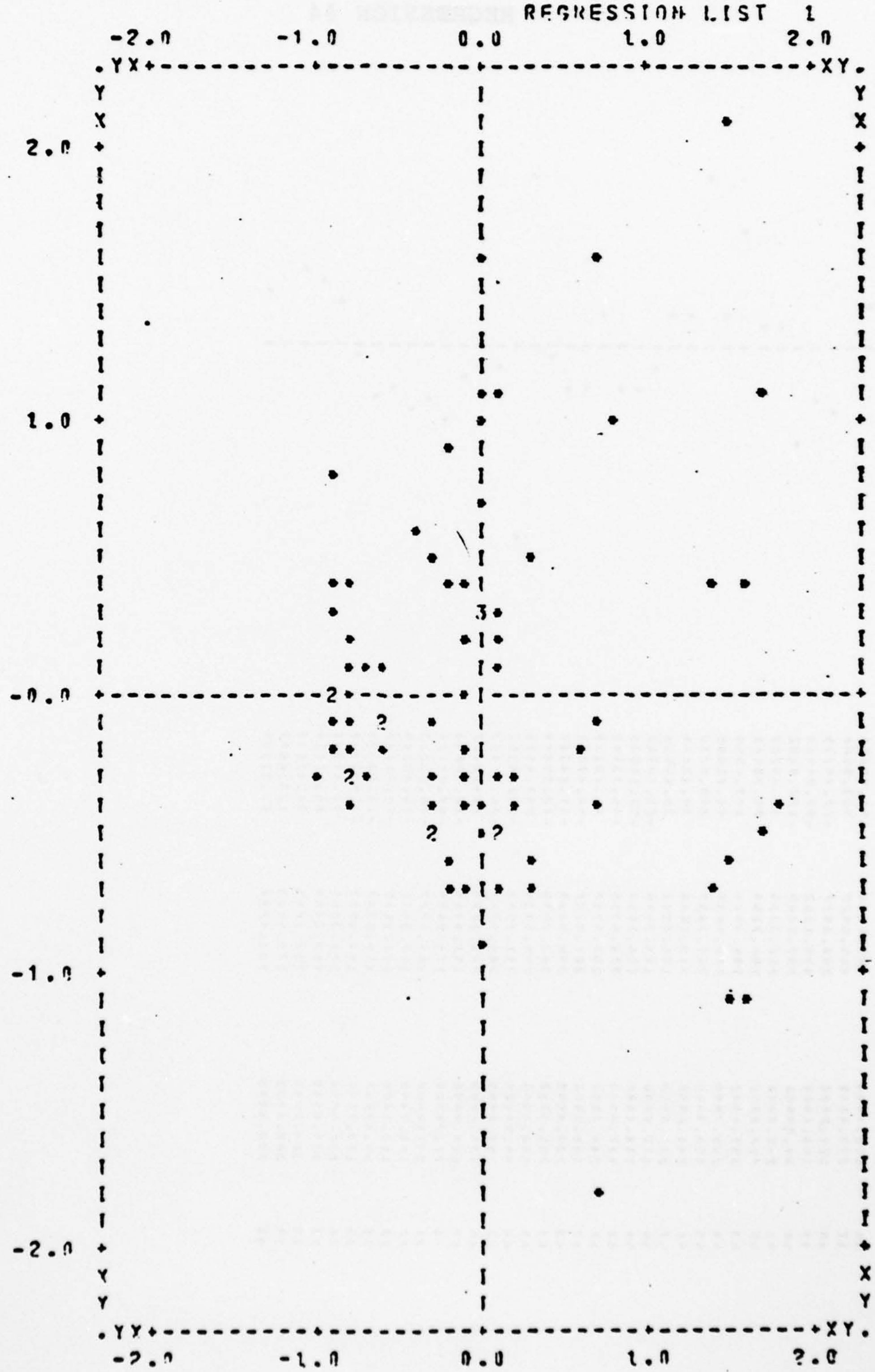
SEQNUM	OBSERVED C13	PREDICTED C13	RESIDUAL
1	38.20000	91.77922	-53.57922
2	69.90000	110.9373	-41.03735
3	78.70000	89.30445	-10.60445
4	72.30000	96.56875	-24.26875
5	83.60000	77.41062	6.189377
6	132.4000	79.80539	52.59461
7	71.40000	82.20015	-10.80015
8	116.8000	101.3583	15.44172
9	127.6000	118.1216	9.478357
10	103.8000	127.7807	-23.98071
11	128.2000	84.59492	43.60508
12	116.0000	91.77922	24.22078
13	149.3000	94.17398	55.12602
14	27.00000	70.22633	-43.22633
15	108.0000	115.7769	-7.776876
16	121.9000	113.3321	8.567889
17	54.70000	76.42235	-21.72235
18	195.7000	88.39619	107.3038
19	80.50000	78.81712	1.682881
20	90.00000	93.10571	-3.105714
21	59.10000	95.58048	-36.48048
22	106.6000	119.5281	-12.92814
23	65.70000	100.3780	-34.67801
24	143.3000	219.7421	-76.44207
25	119.5000	217.3473	-97.84731
26	358.2000	212.5578	145.6422
27	133.1000	198.1092	-65.00918
28	87.60000	183.8206	-96.22059
29	142.0000	214.9525	-72.95254
30	158.7000	236.5054	-77.80543
31	222.5000	212.5578	9.942226
32	172.7000	210.1630	-37.46301
33	333.9000	195.7944	138.1056
34	145.8000	243.6897	-97.88973
35	238.3000	186.2154	52.08465
36	141.0000	183.8206	-42.82059
37	194.2000	191.0049	3.195115
38	200.4000	234.1107	-33.71067
39	311.8000	243.6897	68.11027
40	465.6000	417.8559	47.74413
41	277.6000	417.8559	-140.2559
42	293.4000	391.5134	-98.11344
43	578.3000	427.4349	150.8651
44	390.6000	441.8035	-51.20352
45	249.2000	396.3030	-147.1030

REGRESSION #4



46	442.5000	391.5134	50.98656
47	739.4000	405.8920	333.5080
48	321.2000	398.6977	-77.49775
49	354.1000	425.0402	-70.94016
50	84.80000	207.7482	-122.9482
51	250.0000	217.3473	32.65269
52	212.0000	186.2154	25.78465
53	339.4000	195.7944	143.6056
54	245.3000	200.5839	44.71605
55	416.3000	207.7682	208.5318
56	244.6000	210.1630	34.43699
57	234.8000	195.7944	39.00559
58	172.0000	193.3996	-21.39965
59	134.1000	186.2154	-52.11535
60	177.8000	224.5316	-46.73160
61	249.1000	202.9787	46.12129
62	146.5000	202.9787	-56.47871
63	243.4000	298.5430	-55.14302
64	281.4000	293.7535	-12.35349
65	506.0000	298.5430	207.4570
66	48.90000	291.3587	-242.4587
67	257.6000	284.1744	-26.57443
68	434.8000	305.7223	129.0777
69	115.4000	157.4304	-42.03043
70	77.20000	174.2018	-97.00179
71	94.10000	164.6227	-70.52273
72	101.9000	181.3861	-79.48609
73	112.1000	167.0175	-54.91749
74	89.80000	159.8332	-70.03320
75	154.7000	164.6227	-9.922728
76	232.5000	141.3861	91.11391
77	238.8000	152.6489	86.15110
78	304.2000	207.7285	96.47149
79	302.6000	178.9913	123.6087
80	232.0000	164.6227	67.37727

DEPENDENT VARIABLE C13 VARIABLE LIST 1
REGRESSION LIST 1



APPENDIX D

AFTO FORM 349

MAINTENANCE DATA COLLECTION RECORD

OMB NO. 21-R0227

1. JOB CONTROL NO.	2. WORK CENTER	3. I.D. NO./SERIAL NO.	4. MDS	5. EQ/CL	6. TIME	7. PRI	8. SORTIE NO.	9. LOCATION

10. ENG. TIME	11. ENGINE I.D.	12. INST ENG TIME	13. INST. ENG. I.D.	14.	15.	16	17. TIME SPC REQ	18. JOB STD.

19. FSC	20. PART NUMBER	21. SER. NO./OPER. TIME	22. TAG NO.	23. INST. ITEM PART NO.	24. SERIAL NUMBER	25. OPER. TIME

LINE	A TYPE MAINT	B COMP POS	C WORK UNIT CODE	D ACTION TAKEN	E WHEN DISC	F HOW MAL	G UNITS	H START HOUR	I STOP DAY	I STOP HOUR	J CREW SIZE	K CAT LAB	L CMD ACT ID	M SCH CODE	N EMPLOYEE NUMBER
1												–			
2															
3															
4															
5															

26. DISCREPANCY

27. CORRECTIVE ACTION

28. RECORDS ACTION

AFTO FORM DEC 74 349 TEST

AFLC–WPAFB–JAN 75 400

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Andrews, Frank M., and others. *A Guide for Selecting Statistical Techniques for Analyzing Social Science Data*. Ann Arbor: University of Michigan Press, 1976.

2. Brown, Captain Paul E., USAF. Corrosion Monitor, Hq PACAF/LGMWE, APO San Francisco 96553. Intermittent personal interviews. 20 March through 24 March 1977.

3. Brownlow, C. "AFSC Gears for New Programs," *Aviation Week*, July 15, 1974, pp. 20-28.

4. Clark, Charles T., and Lawrence L. Schkade. *Statistical Analysis for Administrative Decisions*. 2d ed. Cincinnati: South-Western Publishing Co., 1974.

5. Clark, Captain Peter, USAF, ed. "Your Enemy, Corrosion," *Airscoop*, November, 1976, pp. 2-5.

6. Coll, A1C Raymond, USAF. Squadron Weather Specialist, Environmental Technical Applications Center, Scott AFB IL. Telephone interview. 12 May 1977.

7. Furrow, Master Sergeant Richard D., USAF. Corrosion Control Liaison, PACAFL, APO San Francisco 96263. Intermittent interviews. 20 March through 24 March 1977.

8. Greathouse, Glenn A., and Carl J. Wessel, eds. *Deterioration of Materials*. New York: Reinhold Publishing Corperation, 1954.

9. Jeffreys, Major James V., USAF. Chief, AFLC Corrosion Management Office, MMETC, Warner-Robins AFB GA. Letter, subject: Use of Climatological Data by MMETC, to USAF ETAC/EN, 14 January 1974.

10. Langley, H. "Corrosion . . The Air Craft Cancer," *Maintenance*, Spring, 1977, pp. 33-36.

11. Lawrence, Captain Frederick P., USAF. Instructor and Course Director, Quantitative Methods Department, AFIT/SL, Wright-Patterson AFB OH. AFIT Course 5.32, "Statistics II," Class 1977A. Lectures and intermittent personal interviews. 4 October 1976 through 17 December 1976.

12. Lindsey, Senior Master Sergeant John L., USAF. Contract Monitor, PACAFL, APO San Francisco 96263. Letter, subject: Corrosion Control (PACAF), to PACAF/LGMWE, 2 March 1977.

13. Moore, Major Thomas K., USAF. "Corrosion and Fatigue: Problems in Life Cycle Costing," *Defense Management Journal*, January, 1976, pp. 48-53.

14. ________. "Corrosion Problems Encountered During Acquisition of AF Weapons Systems," *Proceedings of the AFOSR/AFML Corrosion Workshop*. Contract F33615-73-C-5084, University of Cincinnati, Cincinnati, OH, July, 1976, pp. 22-53.

15. ________. "Environmental Effects on Maintenance Costs for Aircraft Maintenance." Unpublished technical report AFML-TR-76-31, Air Force Materials Laboratory, Wright-Patterson AFB OH 1976.

16. Nie, Norman H., and others. *Statistical Package for the Social Sciences*. 2d ed. New York: McGraw-Hill Book Co., Inc., 1975.

17. Sellers, Major Donald R., USAF, and Captain Frank L. Harmon, USAF. "A Cost Effectiveness Study of a Consolidated Corrosion Control Work Center." Unpublished master's thesis. SLSR 34-76B, AFIT/SL, Wright-Patterson AFB OH 1976. AD 32297.

18. Setter, Colonel L. C., USAF. "AFLC's Corrosion and Maintenance Problems," *Proceedings of the AFOSR/AFML Corrosion Workshop*. Contract F33615-73-C-5084, University of Cincinnati, Cincinnati, OH, July, 1976, pp. 10-19.

19. Summitt, Dr. Robert. "Corrosion Prediction for Aircraft Maintenance Scheduling." Unpublished research proposal, unnumbered, Michigan State University, East Lansing MI, 1975.

20. Summitt, Dr. Robert. "Corrosion Prediction for Aircraft Maintenance and Scheduling." Unpublished interim report, Contract No. F33615-75-C-5284, Michigan State University, East Lansing MI, 1976.

21. Thompson, William A. "Corrosion: A Billion Dollar Waste," *Aerospace Safety*, February, 1975, pp. 21-23.

22. U.S. Department of the Air Force. *Corrosion Prevention and Control*. TO 1-1-2, 1 January 1973. Washington: Government Printing Office, 1973.

23. ________. *Corrosion Prevention and Control Program*. AFR 400-44. Washington: Government Printing Office, 1974.

24. ________. "Corrosion Prevention and Control (Rivet Bright)," CSAF DC/LG message, May 6, 1975.

25. ________. *Maintenance-Engineering Corrosion Control Program*. PACAF Regulation 66-19, 3 December 1976. Headquarters Pacific Air Forces, APO San Francisco 96553, 1976.

26. ________. *Management Engineering Policies and Procedures*. AFM 25-5, 8 August 1973. Washington: Government Printing Office, 1973.

27. ________. "Management for Reduction of Corrosion Damage and Cost," *TIG Brief*, 28 March 1975, pp. 13-14.

28. ________. *Program Management Directive for Maintenance Posture Improvement Program*. Headquarters, United States Air Force, Washington, D. C., September 9, 1974.

29. ________. *Standard Facility Requirements*. AFM 86-2, 2 June 1975. Washington: Government Printing Office, 1975.

30. Wonnacott, Thomas H., and Ronald J. Wonnacott. *Introductory Statistics for Business and Economics*. New York: John Wiley & Sons, Inc., 1973.

B. RELATED SOURCES

Atkinson, J. J. "Arrest Corrosion," *Maintenance*, Spring, 1976, pp. 46-51.

Bosich, Joseph F. *Corrosion Prevention for the Practicing Engineer*. New York: Barnes and Noble, Inc., 1970.

"New Technique for Detecting Corrosion Offers Cost Savings," *Aviation Week and Space Technology*, May 31, 1976, pp. 43-47.

U.S. Department of the Air Force. *Application of Organic Coatings, Aerospace Equipment*. TO 1-1-8, 1 October 1973. Washington: Government Printing Office, 1973.

________. *Cleaning of Aerospace Equipment*. TO 1-1-1, 1 October 1973. Washington: Government Printing Office, 1973.

________. "Corrosion Prevention and Control," *TIG Brief*, July 4, 1975, p. 21.

________. *Maintenance Management*. AFM 66-1, 1 November 1975. Washington: Government Printing Office, 1975.